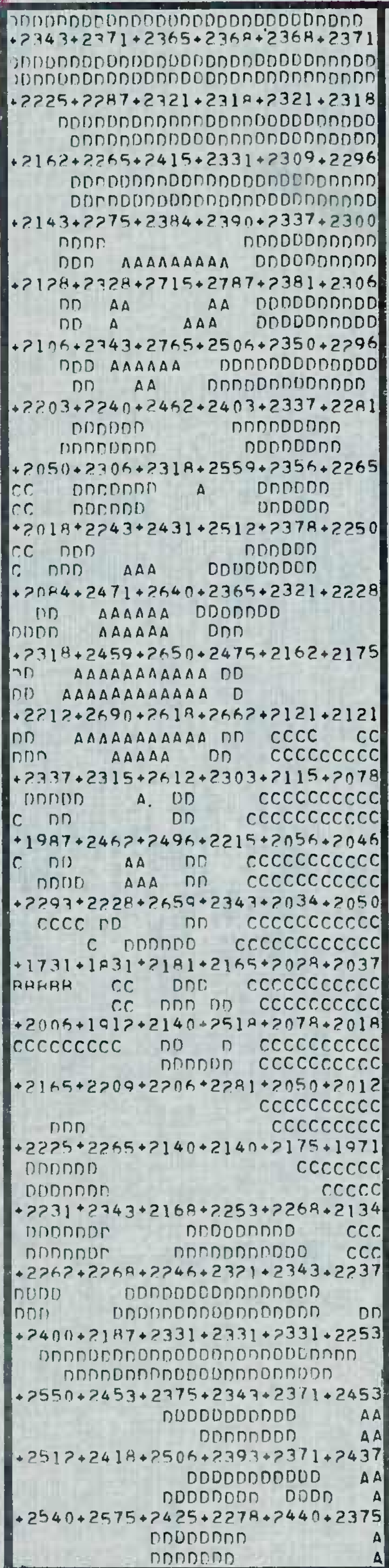

ANNUAL CYCLES OF HEAT IN THE NORTHERN HEMISPHERE OCEANS AND HEAT DISTRIBUTION BY OCEAN CURRENTS

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FLEET NUMERICAL WEATHER CENTRAL

MONTEREY, CALIFORNIA

ANNUAL CYCLES OF HEAT IN THE NORTHERN HEMISPHERE OCEANS AND HEAT DISTRIBUTION BY OCEAN CURRENTS

Summary of annual heat exchange cycles and heat storage in the surface layers of the oceans, including quantitative consideration of heat transport by ocean currents.

by

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ABSTRACT (AND SUMMARY)

This is an interim report on some studies of sea/air interaction and application of the results.

The formulas used in the synoptic computation of heat exchange are reviewed and the results compared to some earlier work, demonstrating good agreement with the results of Shellard (1962). The synoptic heat exchange analyses are compared to mean charts demonstrating the smoothing of features. It is concluded that 10 and 15-day mean charts promise to become useful tools in medium range forecasting.

Monthly mean total heat exchange charts for 1966 and 1967 are presented, the essential features are described and year-to-year changes are pointed out.

The sensible plus latent and total heat exchange is summarized by oceanic regions and the local differences in annual cycles are described, indicating the main source regions of moisture and heat.

The mean annual heat storage change in the Northern Hemisphere oceans is computed, showing that the greatest change occurs in the surface layers above 60m and along the major warm currents.

Finally, the net heat budget for different oceanic regions in 1967 has been computed and estimates have been made on the heat transport by ocean currents to balance the budget in regions of heat deficit.

The sea-air interactions in respect to atmospheric circulations are described in two following reports in this series.

1. PURPOSE OF THE PAPER AND MANNER OF PRESENTATION

Twelve-hourly synoptic heat exchange computations for Northern Hemisphere oceans have been made at Fleet Numerical Weather Central (FNWC), Monterey, California, since 1965. They have been used mainly as input to oceanographic analyses/forecasts, and in studies on their possible use in atmospheric forecasts. A series of three Technical Notes, of which this is the first, analyze briefly the usefulness of the heat exchange and sea-air interaction computations in general, summarize the past results and indicate future plans. The purposes of this first summary are:

(1) To summarize the methods used for computation and the shortcomings of data and to compare the results with other work.

(2) To compare synoptic computations with monthly means and study some special features in monthly means (persistency and year to year variations).

(3) To compare the annual cycles of heat exchange in various regions and investigate causes of differences in these cycles.

(4) To compute the mean annual heat storage change in the Northern Hemisphere oceans and the quantitative transport of heat by ocean currents.

The data and analyses which form the basis of this study are voluminous; only a fraction are presented here in order to make the paper as brief and interesting as possible. The figures are not described in detail, but they are referred to for substantiation of conclusions.

Acknowledgements

The authors express their gratitude to Captain W. E. Hubert, USN, for his advice and criticism during the preparation of this paper and to Graphic Aids Division, DLIW, Presidio of Monterey, California, for reproducing this report. This study has been partially supported by the U. S. Naval Ship Systems Command (012800).

2. SYNOPTIC HEAT EXCHANGE COMPUTATIONS AND COMPARISON OF RESULTS

Synoptic computations of heat exchange between the atmosphere and the ocean have been made twice daily at FNWC since 1965. Figure 1 shows an example of a synoptic Q_{e+h} (sum of latent and sensible heat exchange) computation while Figure 2 presents an example of total (or net) heat exchange at a specific synoptic time. The formulas used in these computations are given in Table 1. Their accuracy has been described earlier by Laevastu (1965) and Laevastu, Clarke and Wolff (1969). Some typical values of different heat exchange components are given in Table 2.

The sensible and latent heat are the main components of energy feedback from the oceans to the atmosphere. Therefore, they are summed and plotted in one chart. It could be noted that Q_h (sensible heat exchange) is usually 15 to 30% of Q_e (latent heat exchange).

Shellard (1962) has published detailed heat exchange computations at Weather Ships I and J in the Atlantic. His eight year monthly mean values of Q_{e+h} and Q_{ℓ} are reproduced in Figures 3 to 6 together with the corresponding monthly mean values for 1967, computed at FNWC. The differences between Shellard's 8-year mean values and FNWC 1967 values are in general within the range of the year-to-year variations indicated by Shellard. It could be noted that the total heat gain obtained during the summer by FNWC is somewhat higher than by Shellard. This difference might be attributed to differences in the manner in which cloud cover is handled. Hankimo (1964) also found that Laevastu's (1960) formula for insolation gives somewhat higher values at lower latitudes than the measured values.

3. SOME PROPERTIES OF SYNOPTIC AND MEAN CHARTS

It has been shown earlier (Laevastu, 1965) that monthly mean (or other mean) values of heat exchange components must be computed by summing the synoptic (12-hourly) heat exchange computations computed from synoptic meteorological parameters and not by averaging the meteorological parameters prior to computations of (monthly) mean charts. This is primarily due to the nonlinearities in the relations presented in the formulas in connection with the short-term variability of meteorological elements and secondarily, as a consequence of the fact that most of the empirical formulas used in such computations have been derived and verified on the basis of short-term measurements.

It is of some interest to examine the change in the nature of the mean charts with an increase of the averaging periods. An examination of Figures 2, 7, 8 and 9 to 32 indicates that the longer the averaging period, the "smoother" the mean chart. The monthly mean charts (Figures 9 to 32) only remotely resemble any synoptic situation due to the averaging of moving systems. The slower the synoptic change and the less pronounced these synoptic features are, the closer the mean chart resembles a given synoptic picture. This slower change is, for example, the case with the sea surface temperature and surface currents (see Laevastu and Corkrum, 1968).

Although monthly mean heat exchange charts must be examined and are of some use in studying year-to-year differences in heating and cooling, the 10 and 15-day mean heat exchange charts (see Figure 8) promise to become useful tools in medium range forecasting, for they indicate the more persistent large-scale anomalies better than the monthly mean charts.

4. MONTHLY MEAN TOTAL HEAT EXCHANGE CHARTS FOR 1966 - 1967

The monthly mean total heat exchange charts for 1966 and 1967 are given in Figures 9 to 32. A few essential features of these charts, including the indications of year-to-year differences are pointed out below.

In January the oceans lose heat north of about 10°N. The heat loss is larger in higher latitudes and along the continents (especially along the eastern coasts of the continents). The most intense heat loss from the oceans during winter occurs along the warm currents at medium latitudes (Gulf Stream, Kuroshio). These latter are also prime areas of heat transport and areas of greatest annual change of heat storage in the oceans (see Chapter 6). The same distribution continues through February with the difference that the maximum heat loss from major currents shifts somewhat further west, especially in the Pacific.

In March the boundary of the heat gain area in the tropics shifts to about 20°N and in April has moved to about 50°N. The heating of all areas of the oceans starts about the middle of April; however, in this month the heat gain of major warm currents is still relatively low. The heat loss from the ocean by evaporation intensifies in April over the western part of the Gulf of Mexico and the Caribbean Sea. These areas are the main source areas of moisture throughout late spring, summer and early autumn. The eastern portion of the Gulf of Mexico shows heat gains in April.

In May all oceans in the Northern Hemisphere gain heat. This gain is greatest along the east coasts of the continents where the loss was largest during the winter season. The same pattern continues through June and July. In August the rate of heating decreases somewhat.

In September cooling has started north of 40°N and in October this cooling boundary has moved to about 25°N. Areas off east coasts of the continents start to cool more than the ocean areas off west coasts. In November the cooling boundary has moved to about 15°N and in December the total heat exchange pattern is very similar to that of January. The following major differences in monthly mean heat exchange in 1966 and 1967 merit mentioning:

In January 1966 the heat loss over major warm currents was larger than in 1967; however, in February 1967 the heat loss over the northern North Pacific was larger than in 1966.

In March 1967 the heat loss in the Central Pacific was again lower than in 1966. This was depicted in surface weather as well (see next report in this series). On the other hand, the heat loss from North Atlantac was considerably greater in March 1967 than in March 1966.

In June to August 1966 the moisture uptake from the Caribbean was more intense than in 1967.

In December 1967 the warm currents lost more heat than in December 1966, thus reversing the situation seen in January.

5. ANNUAL CYCLES OF SENSIBLE AND LATENT AND TOTAL HEAT EXCHANGE IN DIFFERENT OCEAN REGIONS

Some typical annual changes of heat exchange in different areas are shown in Figures 34 to 39; the locations for the areas are given in Figure 33.

As seen from Figures 34 and 35, the annual variation of the heat exchange is greater in higher latitudes (as expected). The evaporation at higher latitudes off the west coast (Figure 34) is considerably less than off the east coast (Figure 36, D). The heat exchange at lower latitudes off the east coast over the warm Gulf Stream (Figure 36, F) shows considerably greater annual variation than the heat exchange at corresponding latitudes off the west coast (Figure 34, 35).

The annual variation of the net heat exchange is considerably greater along the east coast (Figure 37) than along the west coast (Figure 35). The Mediterranean Sea shows lower values of total heat exchange in 1967 due to high evaporation (Figure 36, E).

The heat exchange at mid and low latitudes in the Eastern Atlantic (Figure 38, H,I) is comparable to the heat exchange at the same latitudes in the Eastern Pacific (Figure 34). However, the Norwegian Sea (Figure 38, G) shows large annual variations and great net heat loss.

The heat exchange (both Q_{e+h} and Q_ℓ) were summarized and averaged by large ocean regions; these regions are shown in Figure 40. Figures 41 and 42 show the monthly mean Q_{e+h} for the various regions in the Atlantic and Pacific. In addition to illustrating the facts brought out by Figures 34 to 39, they also show that the main source regions for moisture are the Gulf of Mexico - Caribbean region, the Mediterranean Sea and areas P1 and P2 in the Pacific. Besides a winter maximum in evaporation in the Gulf of Mexico - Caribbean region, there is a smaller secondary maximum in July - August.

In low latitude regions the supply of moisture varies relatively little with season. As these low-latitude ocean regions are large, most of the moisture in the atmosphere originates from them during the summer. During the winter the high-latitude regions provide nearly equal amounts of moisture.

Q_{e+h} averages nearly 50 cal cm^{-2} (24h)$^{-1}$ lower in low-latitude areas in the Pacific compared to the Atlantic. In general the Atlantic provides more moisture to Europe than the Pacific provides to the west coast of North America.

The monthly mean total (or net) heat exchange values for the different oceanic regions (Figures 43 and 44) illustrate the varying supply of heat and the variation in times of maximum and minimum heat gain and loss (as much as 2 months).

6. MEAN ANNUAL STORAGE OF HEAT IN THE OCEAN

The annual heat storage change can be computed by subtracting ocean temperatures (from surface to a level where annual change is negligible) of the coldest month (February) from the warmest month (August). This has been done, using long-term monthly mean temperatures at standard levels, analyzed from available BT and Nansen cast data. These monthly mean temperatures have been prepared by Mrs. M. Robinson, SIO for the Pacific and Miss E. Schroeder, WHOI for the Atlantic.

The total annual heat storage change between February and August from 0 to 120m (by 30m levels) is shown in Figure 45 (k cal cm^{-2}). The largest storage change occurs along the major warm currents. The greatest heat loss during the winter season occurs in the same areas (see Figure 9). Furthermore, as shown by Rodewald (1966), the major long-term changes and anomalies of sea surface temperature occur in the same areas of maximum heat transport in the oceans.

Some preliminary studies at FNWC also indicate that in addition to sea surface temperature anomalies, there are considerable year-to-year variations of heat content in different areas of the oceans. This variation influences long-range weather changes and is the subject of another study to be reported in this series.

Figure 46 gives the annual heat storage change in the 0 to 30m layer, showing that most of the change occurs here. Figures 47 and 48 give the heat storage change in the 30 to 60m and 60 to 90m layers, respectively. The main storage change areas in these layers are still along major currents; however, the storage decreases rapidly with depth. Some areas in the 60 to 90m layer show negative values, indicating that winter is warmer than summer. Figure 49 shows that very little annual storage change takes place in the 90 to 120m layer and that in medium and low latitude areas, this layer is slightly warmer in the winter than in the summer.

7. NET ANNUAL HEAT BUDGETS OF DIFFERENT OCEANIC REGIONS AND HEAT TRANSPORT BY CURRENTS

The mean resultant latent and sensible heat exchange in different oceanic regions during 1967 is given in Figure 50. It illustrates the distribution of feedback of energy from the sea to the atmosphere and the distribution of evaporation. A rough estimate of the evaporation (in mm) can be obtained by subtracting about 25% of the value (for Q_h) and then dividing by 0.06.

The mean latent and sensible heat loss from the oceans varies from about 57 to 150 k cal cm^{-2} per year. The highest Q_{e+h} losses occur in the Mediterranean Sea, Gulf of Mexico, China Sea and in the Norwegian Sea. The high heat uptake from the Norwegian Sea has been noticed by Shuleykin (1968) who advocates an intensive study of heat content and transport by the Norwegian Current and the North Atlantic Drift Current for long-range weather prediction purposes.

Figure 51 gives the mean net heat gain or loss in different oceanographic regions in 1967 (k cal cm^{-2} year). Only three regions show heat gain (A3, P4 and P6). Into all other regions the heat must be transported by ocean currents. Figure 52 summarizes the total heat surplus or deficit of different regions in 1967.

Shellard (1962) has clearly pointed out in quantitative terms the importance of heat transport by ocean currents. He found that about 85% of the heat has to be transported to Weather Ship I's location (the corresponding value for Weather Ship J was 75%). Both Weather Ships are located off major ocean currents, however. A general heat budget summary for North Polar Seas considering heat advection, has been published by Mosby (1963). A simplified model for computation of heat transport by the air and oceans has been proposed by Shuleykin (1968). Dickson and Lee (1969) discuss the importance of heat transport with the following words: "It is clear, therefore, that changes in the atmospheric circulation over the North Atlantic have a dramatic response in the sea itself and that there are possibly feedback effects since the ocean is seen to be actively transporting heat from one place to another and not acting merely as a reservoir."

A brief, quantitative examination of the heat transport is made below. However, this process is the subject of further study at FNWC.

It is of interest to ascertain whether the Gulf Stream is capable of transporting the heat deficit in Atlantic regions A1, A2 and partly A4. The respective heat deficits in 1967 in these regions were 169×10^{-19}, 228×10^{-19} and 104×10^{-19} calories.

Assuming the transport of the Gulf Stream to be $100 \times 10^{6} m^{3} sec^{-1}$ (Warren, 1968) (= $3.15 \times 10^{21} cm^{3} year^{-1}$ and a temperature difference of 5°C between the source and destination regions, a transport of 15.8×10^{21} cal per year is possible. The total heat deficit of the three regions listed above is only 5×10^{21} cal. However, Wunsch, Hansen and Zetler (1969) show that according to Wertheim the mean transport of Florida Current fluctuates between 17 and $39 \times 10^{6} m^{3} sec^{-1}$ with mean value about $28 \times 10^{6} m^{3} sec^{-1}$. This value would give a heat transport of only 4.4×10^{21} cal with the previous assumptions. Knauss (1969) summarized other estimates of volume transport of Gulf Stream, which, excluding two high estimates, vary between 33 and $76 \times 10^{6} m^{3} sec^{-1}$. Thus the values above indicate that the variations in volume transport of Gulf Stream may affect the heat supply to downstream regions.

Assuming a transport of $10 \times 10^6 m^3 sec^{-1}$ for the Alaskan Gyral and a temperature difference of 2°C for source and destination regions, this gyral can transport about 6×10^{20}cal. The heat deficit of the corresponding region is 0.9×10^{20}cal in 1967. Furthermore, assuming a plausible value of $10 \times 10^6 m^3 sec^{-1}$ as the transport through the Faeroer - Shetland Channel (which is somewhat above the average (see Dickson and Lee, 1969)) and a temperature difference of 5°C between the source and destination regions, the heat transport would amount to 1.6×10^{21} calories.

The corresponding heat deficit of the Norwegian Sea in 1967 was about 2.3×10^{21} calories. Obviously some heat is also transported to the Norwegian Sea between Faeroers and Iceland.

The above sample calculations show that (a) major currents are capable of transporting the required heat in high latitudes, (b) the year-to-year fluctuations in transport through some areas such as Faeroer - Shetland Channel and Faeroer - Iceland area can influence considerably the heat storage of the "downstream" areas, such as Norwegian Sea and that these fluctuations would have pronounced effects on the weather during the cooling season. Even the fluctuations of Gulf Stream transport may affect year-to-year variations of heat storage in North Atlantic.

It should be noted that the heat loss from the Norwegian Sea might have been above normal in 1967 (average 73.5 k cal cm^{-2}year). For comparison the corresponding value for region A1 was 44.6 k cal cm^{-2}year, and Hankimo found for the Baltic a mean value of 41 k cal cm^{-2} year.

Of multiple interest would be the question of whether the heat budget of a semiclosed sea, such as the Mediterranean could be balanced and what are the magnitudes of year-to-year differences in this balance. According to Lacombe (1961) the inflow to the Mediterranean is $1.0 \times 10^6 m^3 sec^{-1}$, outflow $0.96 \times 10^6 m^3 sec^{-1}$ and net inflow $0.04 \times 10^6 m^3 sec^{-1}$. This net inflow must evaporate. Thus, assuming a temperature difference of 5° between in and outflowing waters, the inflow provides about 16×10^{19} cal and the net inflow provides only about 0.2×10^{19} cal. Thus either the estimate of the water exchange or of the heat exchange is somewhat in error. (Computations with Hydrodynamical Numerical Model at FNWC give more than twice the amount of inflow to the Mediterranean as compared to the value given above.) On the other hand, a net latent heat loss of 70 kcal cm^{-2} $year^{-1}$ would give an evaporation of 119 cm per year. This value compares favorably with available estimates (145 cm by Schott, 110 cm by Sverdrup, Johnson, Fleming and 90 cm to 145 cm by Wüst) (from Wüst, 1952, Aliverti, de Maio and Picotti, 1959 and Wüst, 1959).

There was a negative sea surface temperature anomaly in the Mediterranean (average - 1.5°C) during the winter of 1967-1968. If this anomaly reached to a depth of 200m it would have accounted for 78×10^{19} calories.

The above examples indicate the need for exact analyses of current transport and ocean thermal structure and its anomalies in connection with heat exchange computations in order to understand the distribution of heat, its seasonal and year-to-year variations and effects on weather. These studies are continuing at FNWC.

Table 1

Formulas for synoptic computation of heat exchange between the sea and the atmosphere

All units of Q's in g cal cm^{-2} $24h^{-1}$

(1) Insolation, $Q_s = 0.014\ A_n t_d\ (1 - 0.0006\ C^3)$

If cloud cover analysis is made in 3 layers

$$Q_s = Q_{os}\ (1 - 0.0075C_L^2)$$

$$Q_s = Q_{os}\ (1 - 0.006C_M^2)$$

$$Q_s = Q_{os}\ (1 - 0.0035C_H^2)$$

(Minimum Q_s applying)

(2) Albedo, $Q_r = 0.15\ Q_s - (0.01\ Q_s)^2$

(3) Effective back radiation $Q_b = (297 - 1.86\ T_w - 0.95U_o)(1 - 0.0765C)$

If cloud cover analysis is made in 3 layers

$$Q_b = Q_{ob}\ (1 - 0.085C_L)$$

$$Q_b = Q_{ob}\ (1 - 0.065C_M)$$

$$Q_b = Q_{ob}\ (1 - 0.030C_H)$$

(Minimum Q_b applying)

(4) Latent heat transfer,

$e_w - e_a$ pos. $Q_e = (0.26 + 0.077\ V)\ (0.98\ e_w - e_a)$

$e_w - e_a$ neg. $Q_e = 0.077\ V\ (0.98\ e_w - e_a)$

(5) Sensible heat transfer,

$T_w - T_a$ pos. $Q_h = 39\ (0.26 + 0.077\ V)\ (T_w - T_a)$

$T_w - T_a$ neg. $Q_h = 3\ V\ (T_w - T_a)$

(6) Total heat exchange, $Q_\ell = Q_s - Q_r - Q_b - Q_e - Q_h$

Table 1 (continued)

Symbols used in Table 1

A_n	-	Noon altitude of the sun (degrees)
C	-	Cloud cover (total) (in tenths)
C_H	-	High cloud cover (in tenths)
C_L	-	Low cloud cover (in tenths)
C_M	-	Medium cloud cover (in tenths)
e_a	-	Water vapor pressure of the air (mb)
e_w	-	Saturation vapor pressure of the sea surface (mb)
Q_b	-	Effective back radiation (g cal cm^{-2} $(24h)^{-1}$)
Q_e	-	Latent heat (transfer)
Q_h	-	Sensible heat (transfer)
Q_ℓ	-	Total (net) heat exchange
Q_{ob}	-	Effective back radiation to clear sky
Q_{os}	-	Insolation with clear sky
Q_r	-	Albedo (reflected radiation)
Q_s	-	Insolation
t	-	Length of the daylight (min.)
T_a	-	Temperature of the air (°C)
T_w	-	Temperature of the water (°C)
U_o	-	Relative humidity (%)
V	-	Wind speed (m sec^{-1})

Table 2

Normal ranges and typical values of heat exchange components, and size of heat exchange patterns

Component	Normal range g cal cm^{-2} $(24h)^{-1}$	Typical values (usually at 30°N) g cal cm^{-2} $(24h)^{-1}$ Average	Winter	Spring	Summer	Fall	Relative pattern size (and other remarks)
Insolation-reflected radiation $(Q_s - Q_r)$	100 to 780	450	280	600	700	250	1/2 cyclone; 1/4 anticyclone (determined by latitude and cloudiness patterns)
Effective back radiation (Q_b)	30 to 240	100	130		70		About the size of atmospheric systems
Exchange of sensible heat (Q_h)	-50 to 300	50	70	40	30	80	About 1/2 size of atmospheric systems. Small intense, but rapidly changing patterns possible near coasts and near sharp current boundaries.
Exchange of latent heat (Q_e)	-50 to 850	260	Seasonal patterns vary in different areas (See Q_ℓ below)				As above.
Total (or net) heat exchange (Q_ℓ)	-850 to 650						About 1/2 size of cyclones and 1/4 size of anticyclones. Rapidly changing smaller patterns possible in tropical storms, at coasts and occasionally at sharp current boundaries.
Eastern part of oceans (Q_ℓ)			0	300	500	-80	
Central part of oceans (Q_ℓ)			80	200	400	-200	
Western part of oceans (Q_ℓ)			-400	-100	50	-600	

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FIGURE 1 SUM OF LATENT AND SENSIBLE HEAT EXCHANGE ON 00Z 4 NOV. 1968

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

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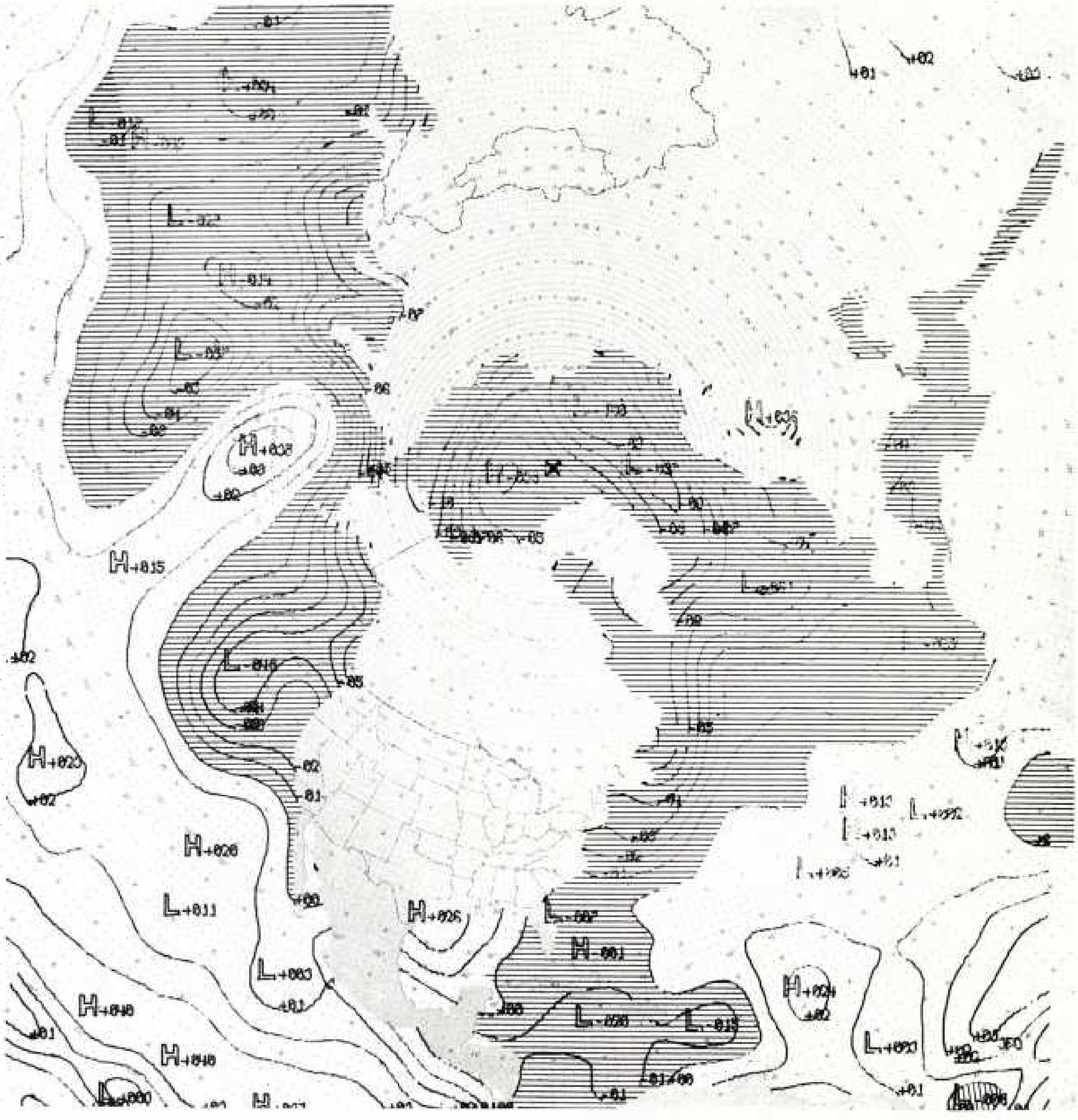

FIGURE 2 TOTAL HEAT EXCHANGE ON 00Z 13 MARCH 1967 (AREAS OF HEAT LOSS FROM THE OCEANS ARE HATCHED)

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE .
SCALE: 1:60,000,000

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CHART No. 6B-1

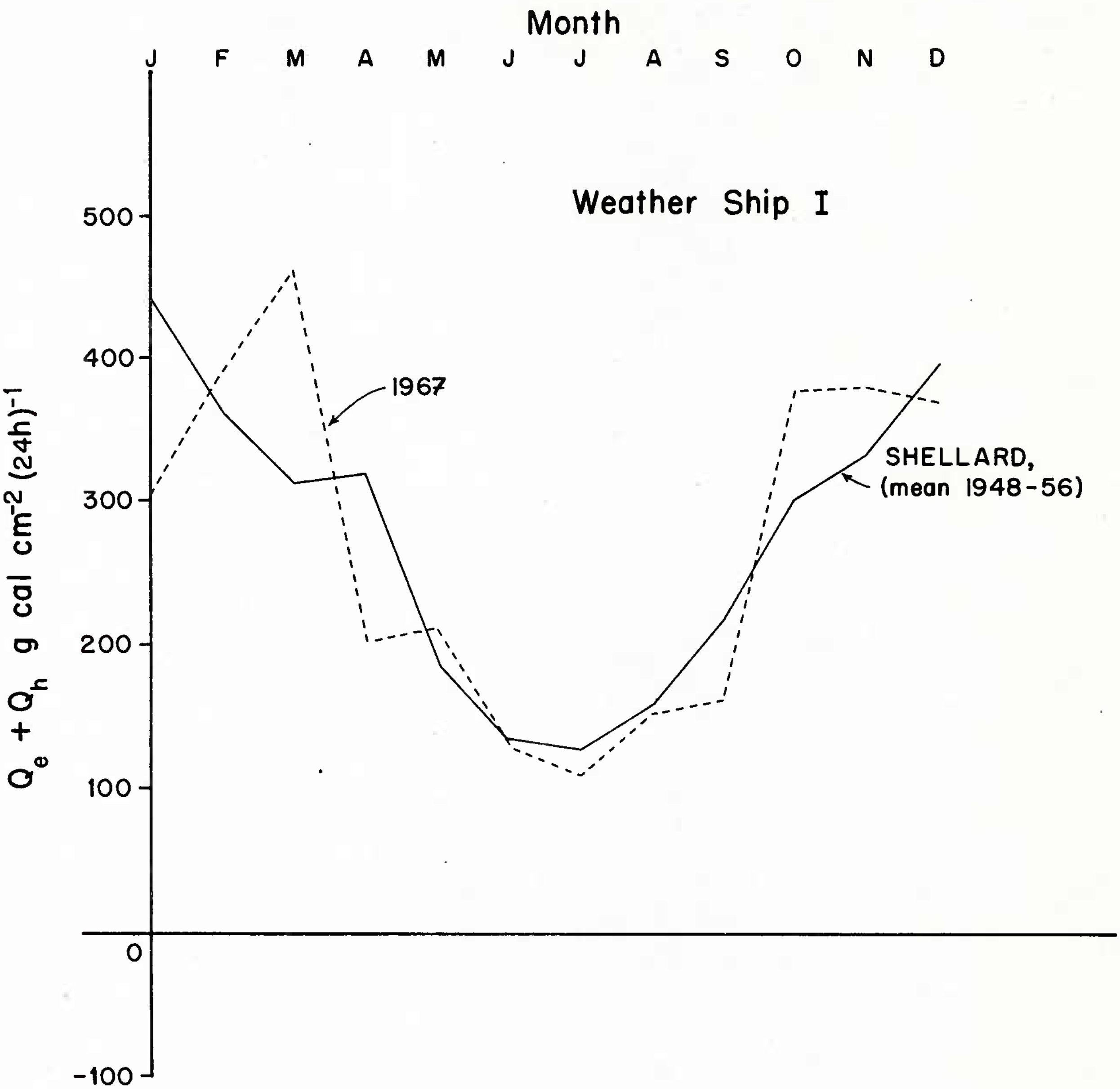


FIGURE 3 MONTHLY MEAN SENSIBLE AND LATENT HEAT EXCHANGE AT WEATHER SHIP "I" IN THE ATLANTIC IN 1967 AS COMPARED TO 8-YEAR MEAN COMPUTED BY SHELLARD IN 1962

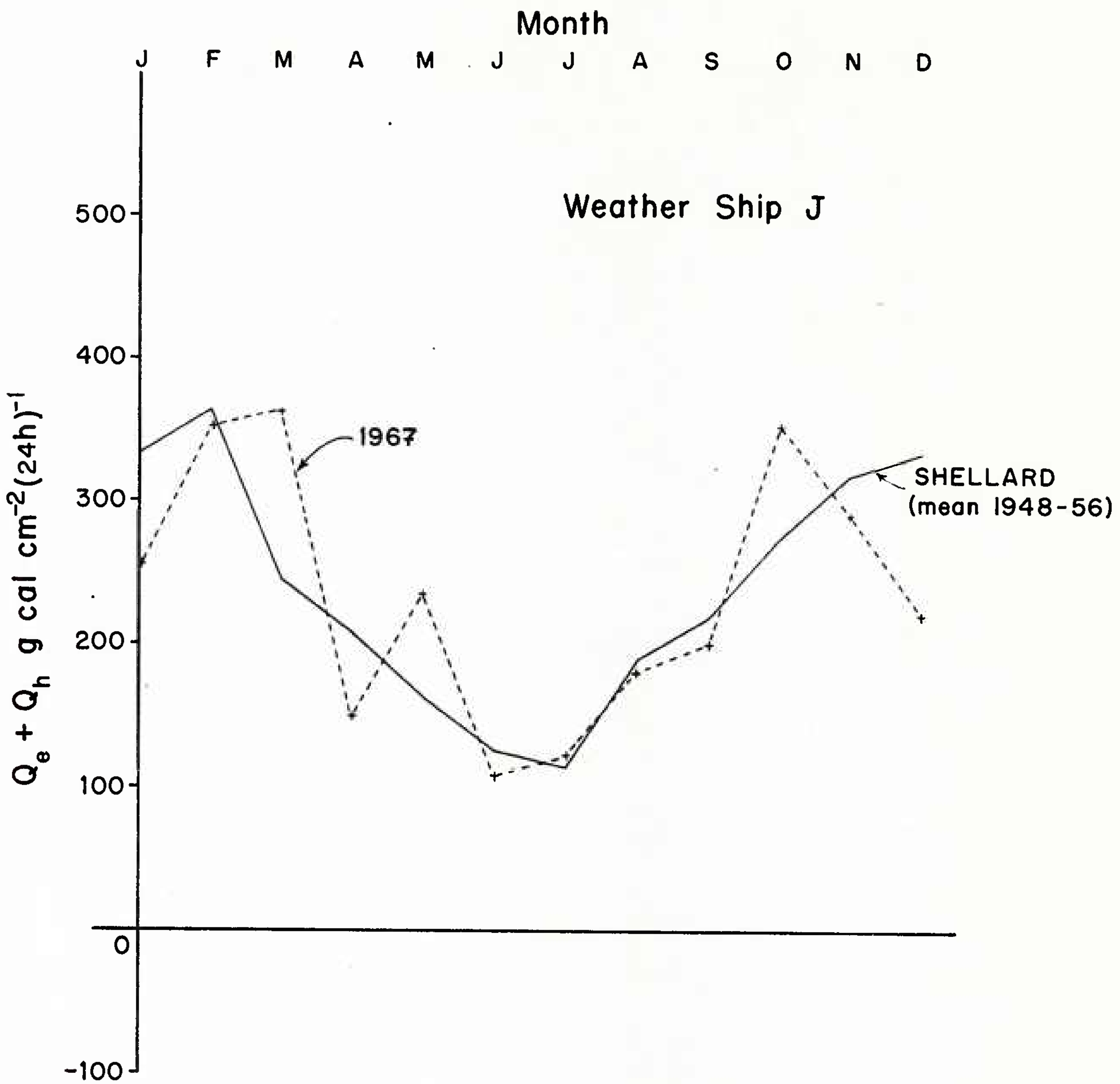


FIGURE 4 MONTHLY MEAN SENSIBLE AND LATENT HEAT EXCHANGE AT WEATHER SHIP "J" IN THE ATLANTIC IN 1967 AS COMPARED TO 8-YEAR MEAN COMPUTED BY SHELLARD IN 1962

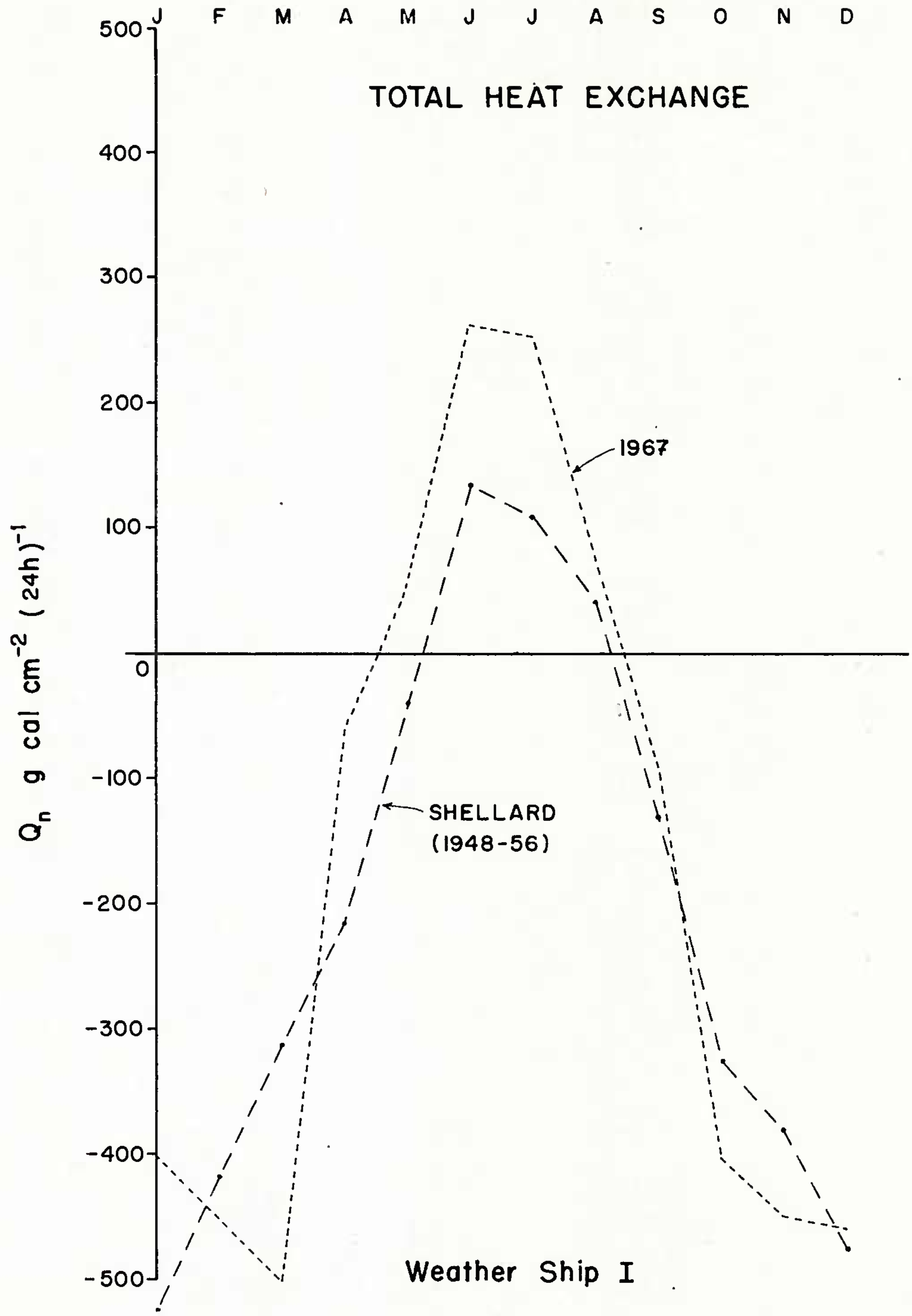


FIGURE 5 MONTHLY MEAN TOTAL HEAT EXCHANGE AT WEATHER SHIP "I" IN THE ATLANTIC IN 1967 AS COMPARED TO 8-YEAR MEAN COMPUTED BY SHELLARD IN 1962

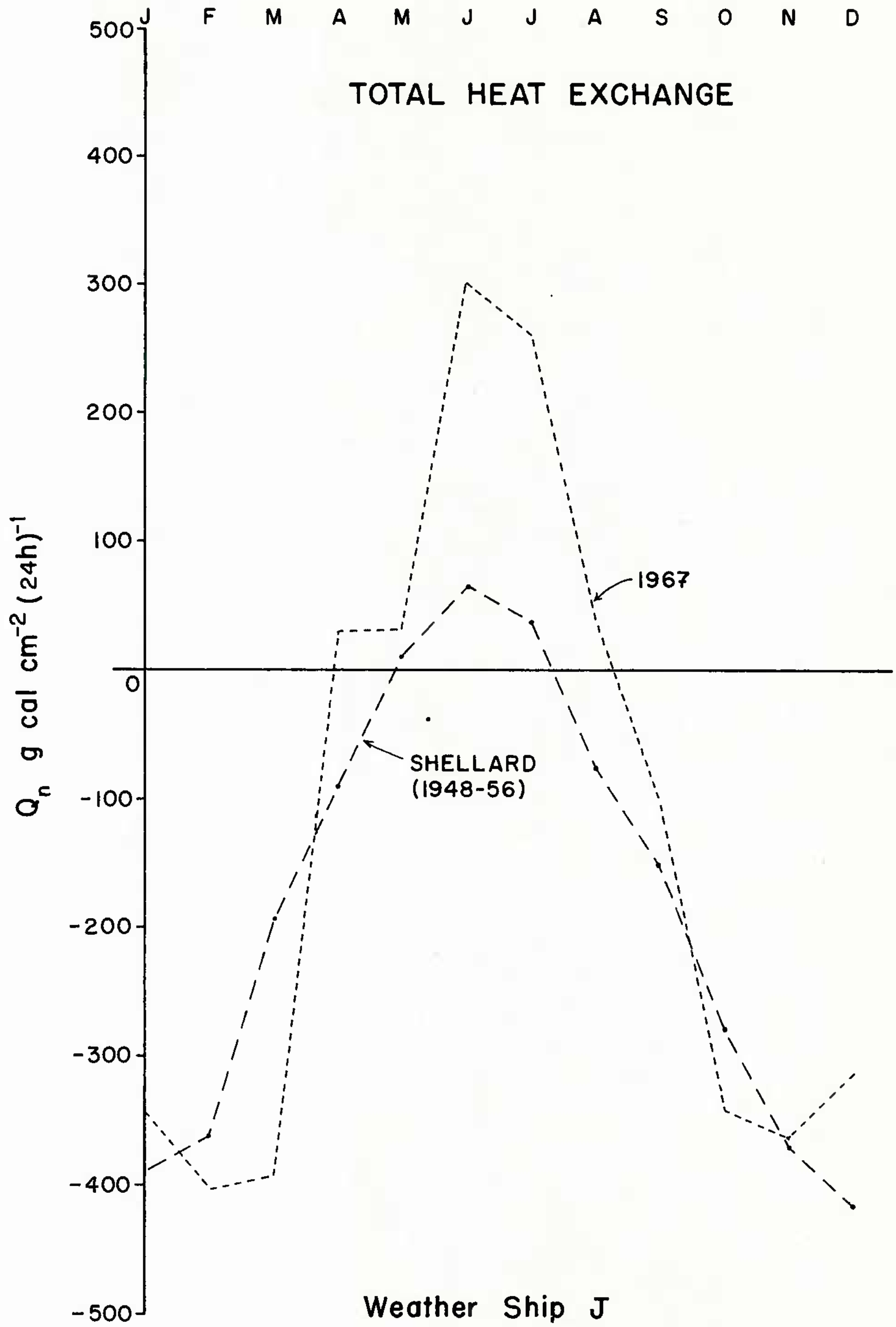


FIGURE 6 MONTHLY MEAN TOTAL HEAT EXCHANGE AT WEATHER SHIP "J" IN THE ATLANTIC IN 1967 AS COMPARED TO 8-YEAR MEAN COMPUTED BY SHELLARD IN 1962

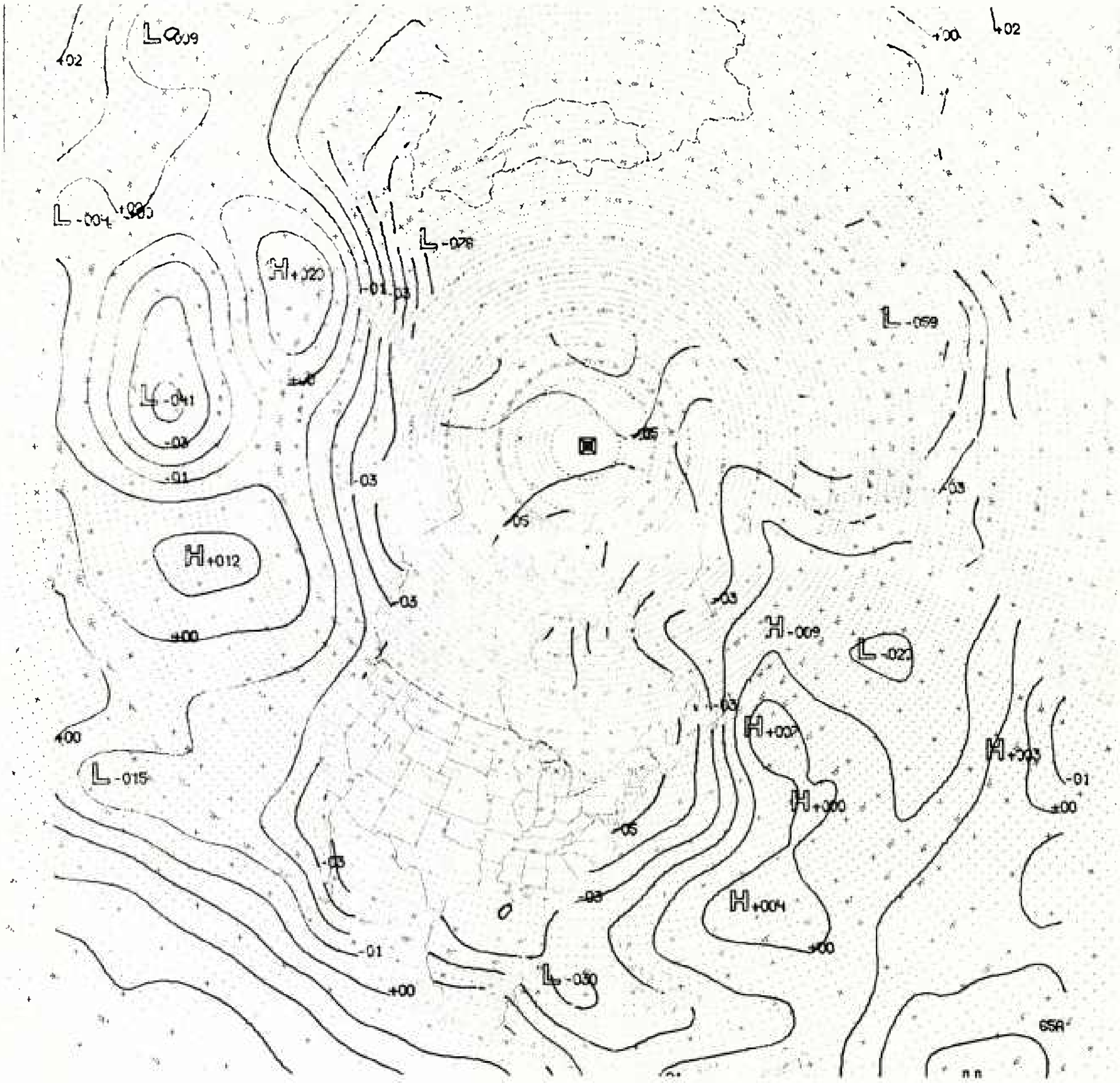


FIGURE 7 5-DAY MEAN TOTAL HEAT EXCHANGE FROM 15 TO 20 OCTOBER 1969

PROJECTION. POLAR STEREOGRAPHIC – TRUE AT 60 NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER CENTRAL
MONTEREY, CALIFORNIA

CHART No. 6B-1

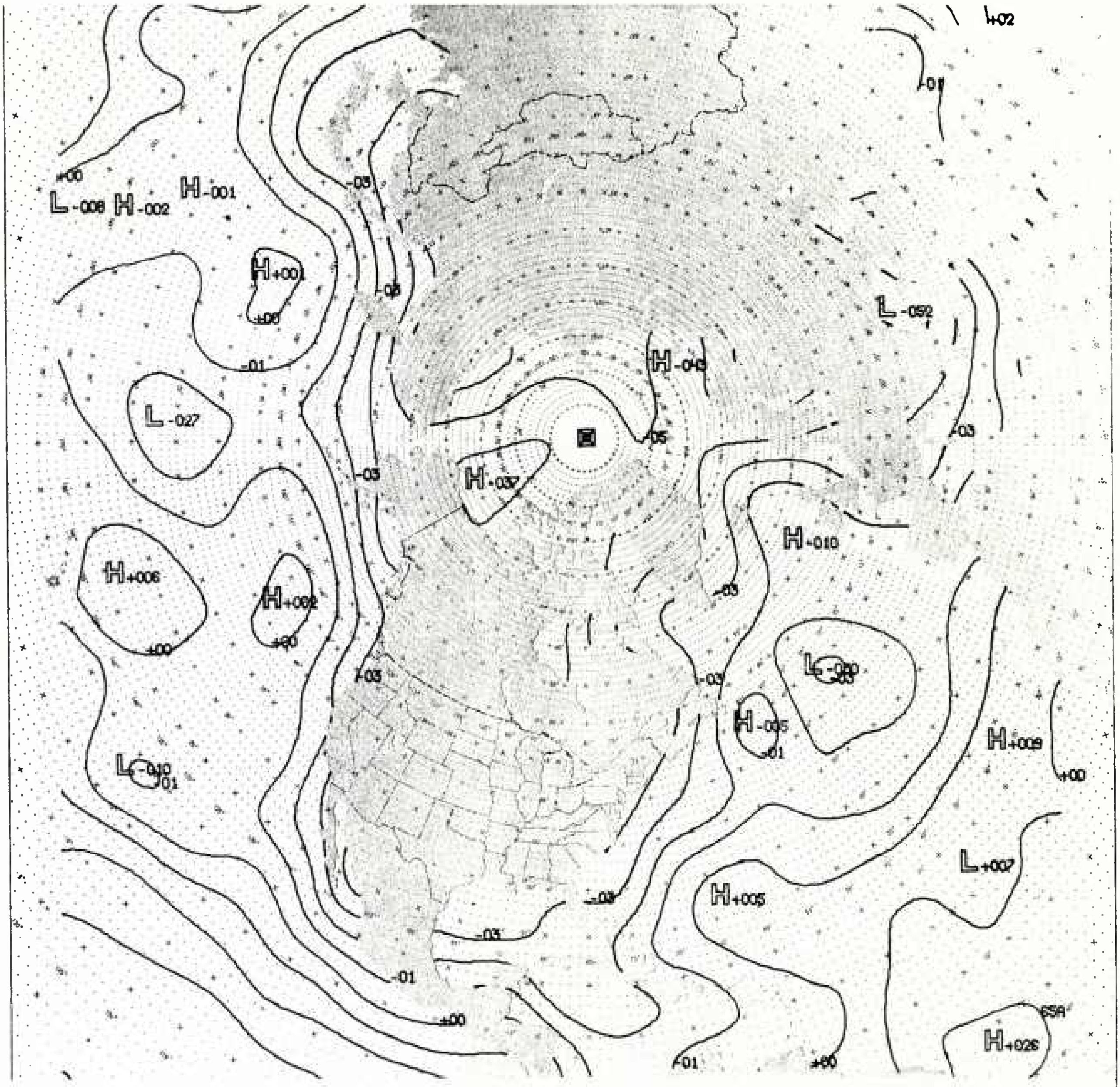
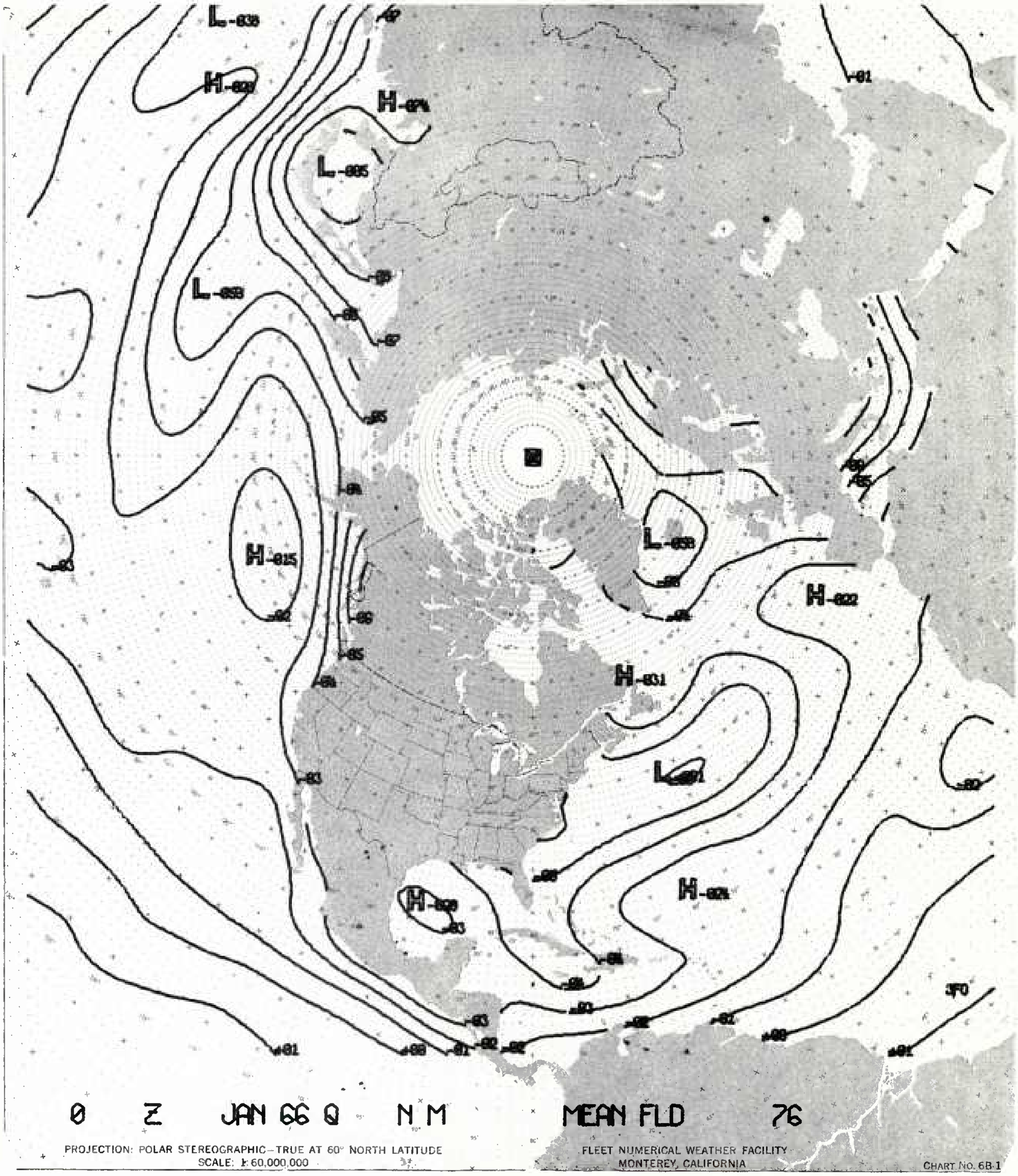


FIGURE 8 10-DAY MEAN TOTAL HEAT EXCHANGE FROM 10 TO 20 OCTOBER 1969

PROJECTION: POLAR STEREOGRAPHIC–TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER CENTRAL
MONTEREY, CALIFORNIA

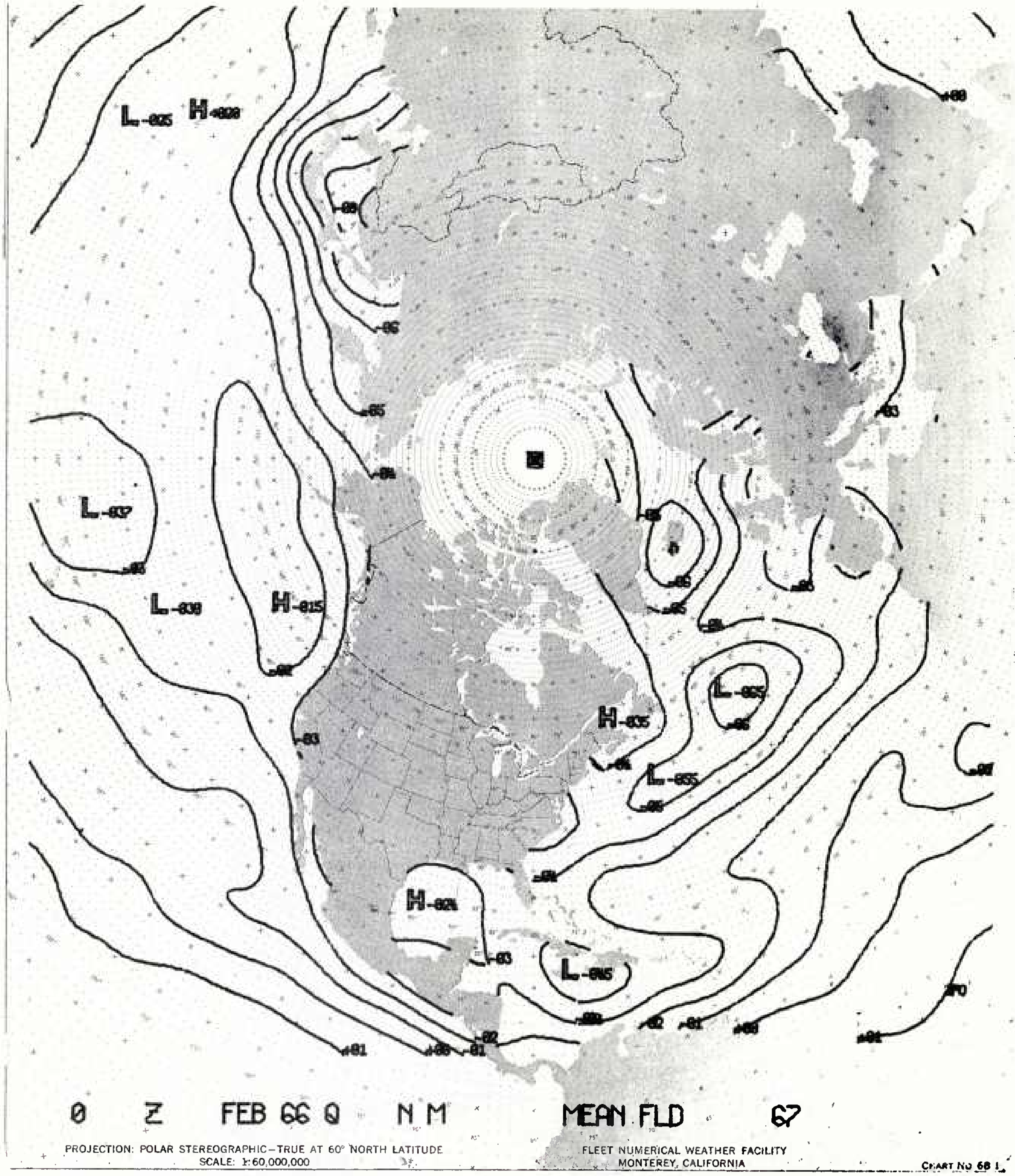
CHART No. 6B-1

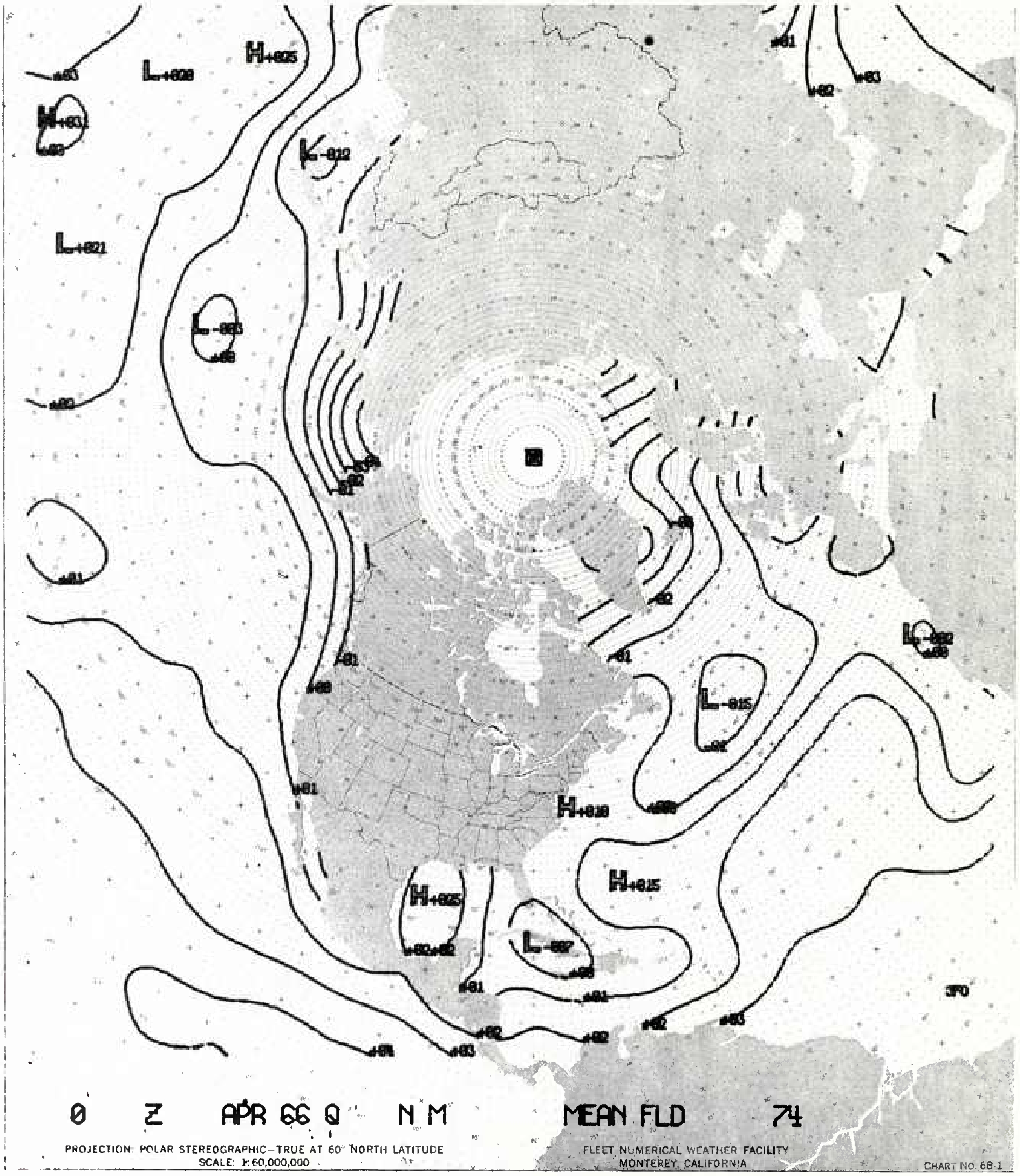


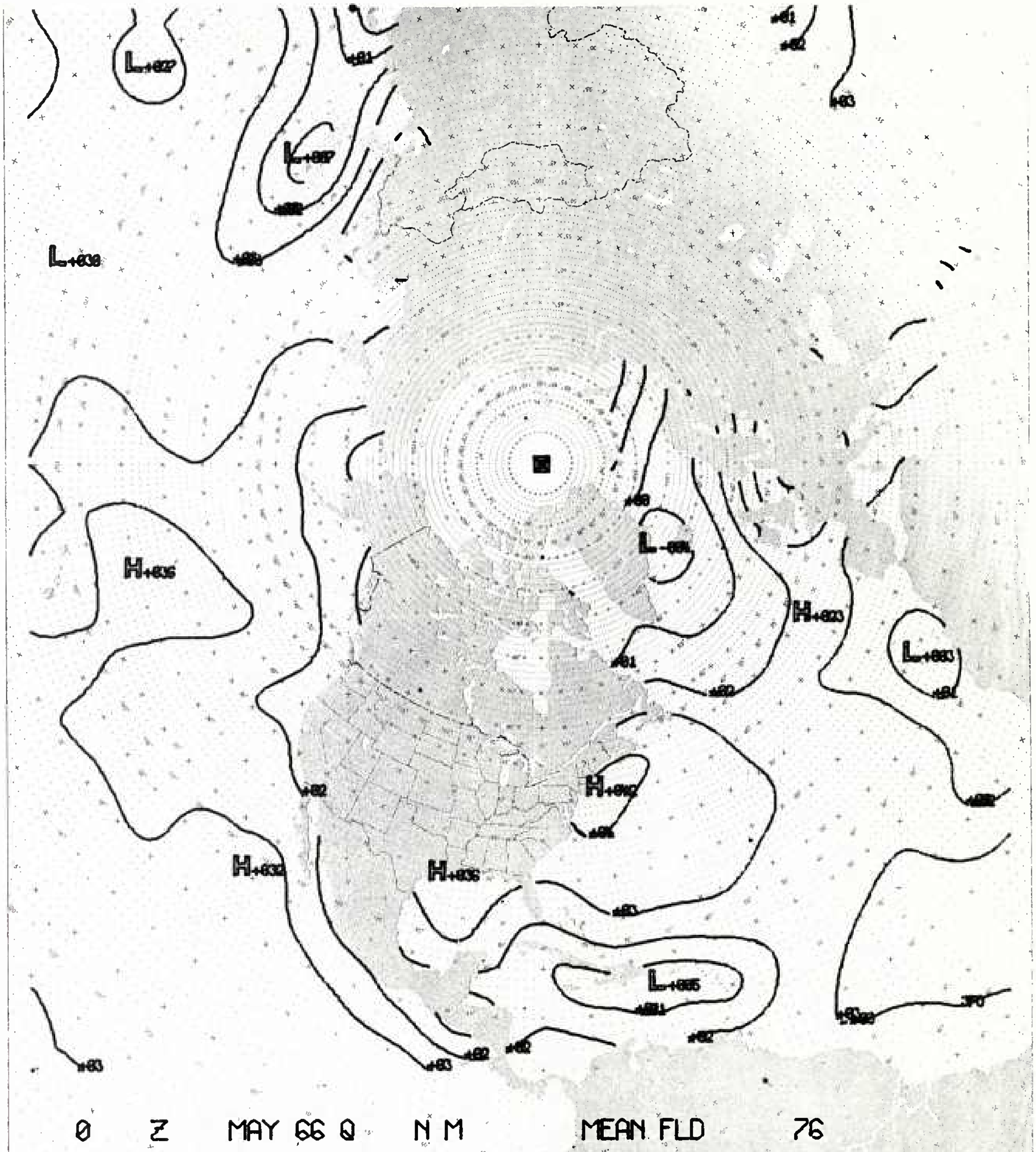
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART No. 6B-1


0 Z FEB 66 Q NM MEAN FLD 67
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000
FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA
CHART No 68 1

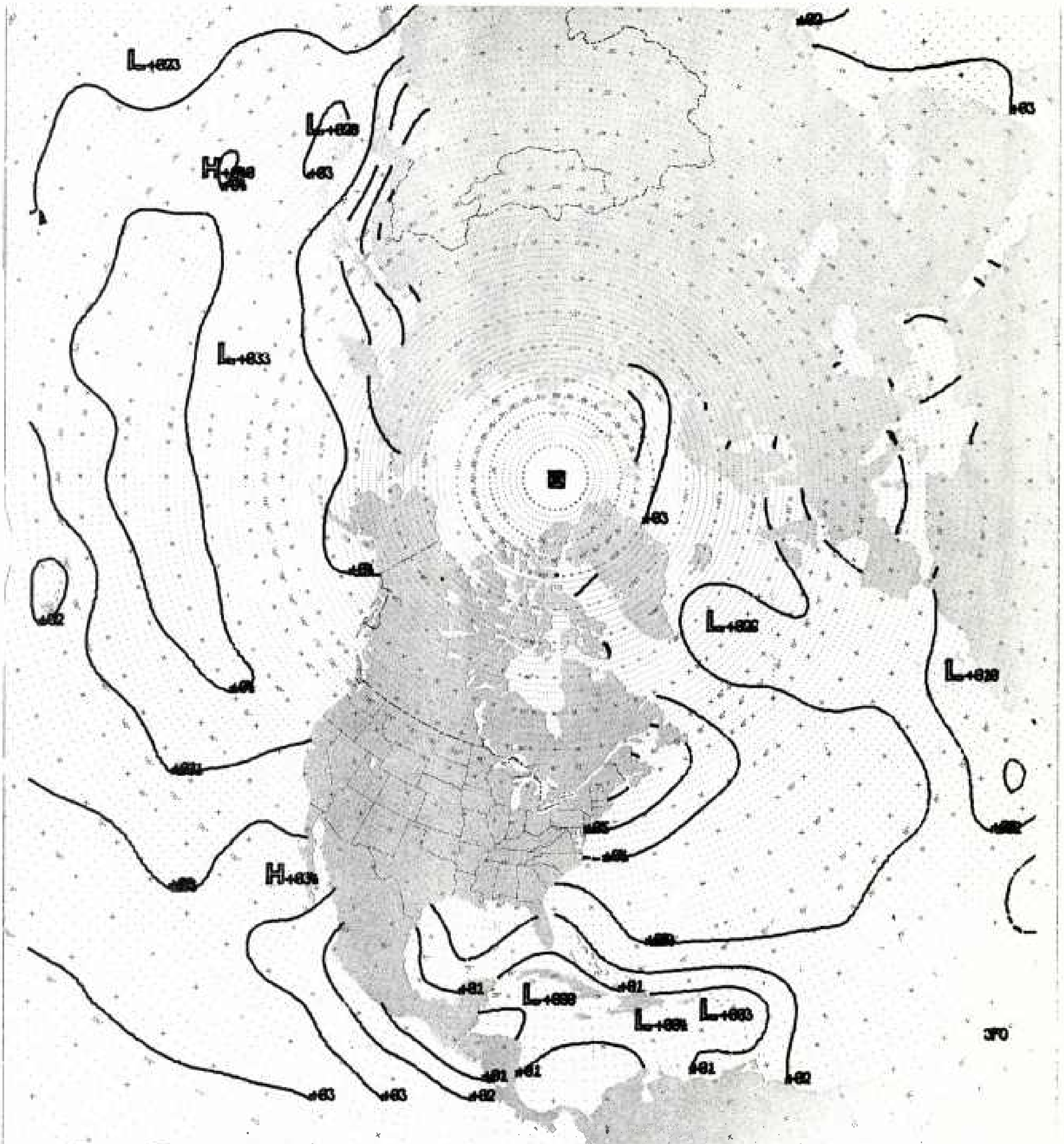

0 Z APR 66 Q N M MEAN FLD 74
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000
FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA
CHART NO. 6B-1



PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

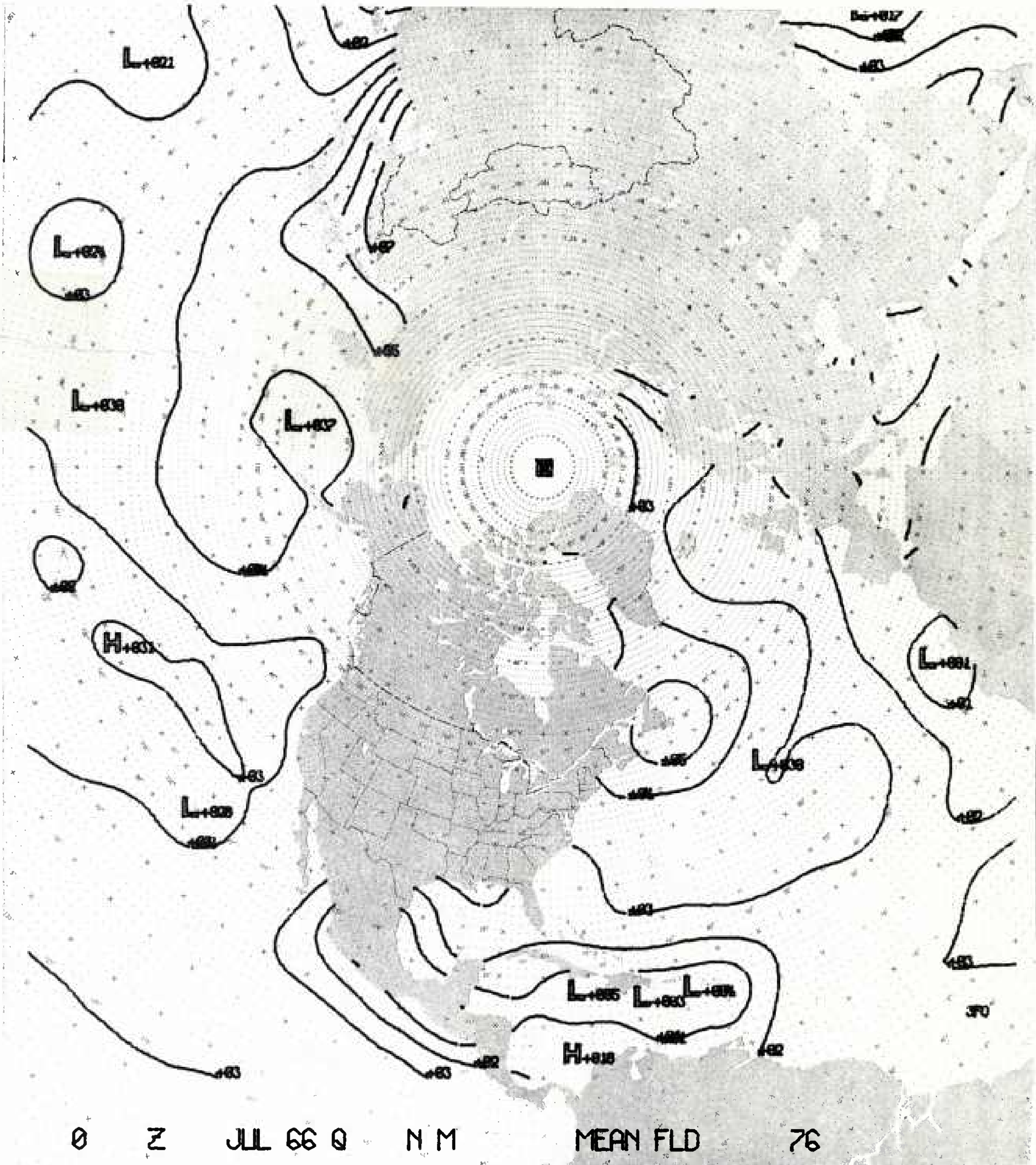
CHART No. 6B



0 Z JUN 66 Q N M MEAN FLD 74

PROJECTION: POLAR STEREOGRAPHIC–TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

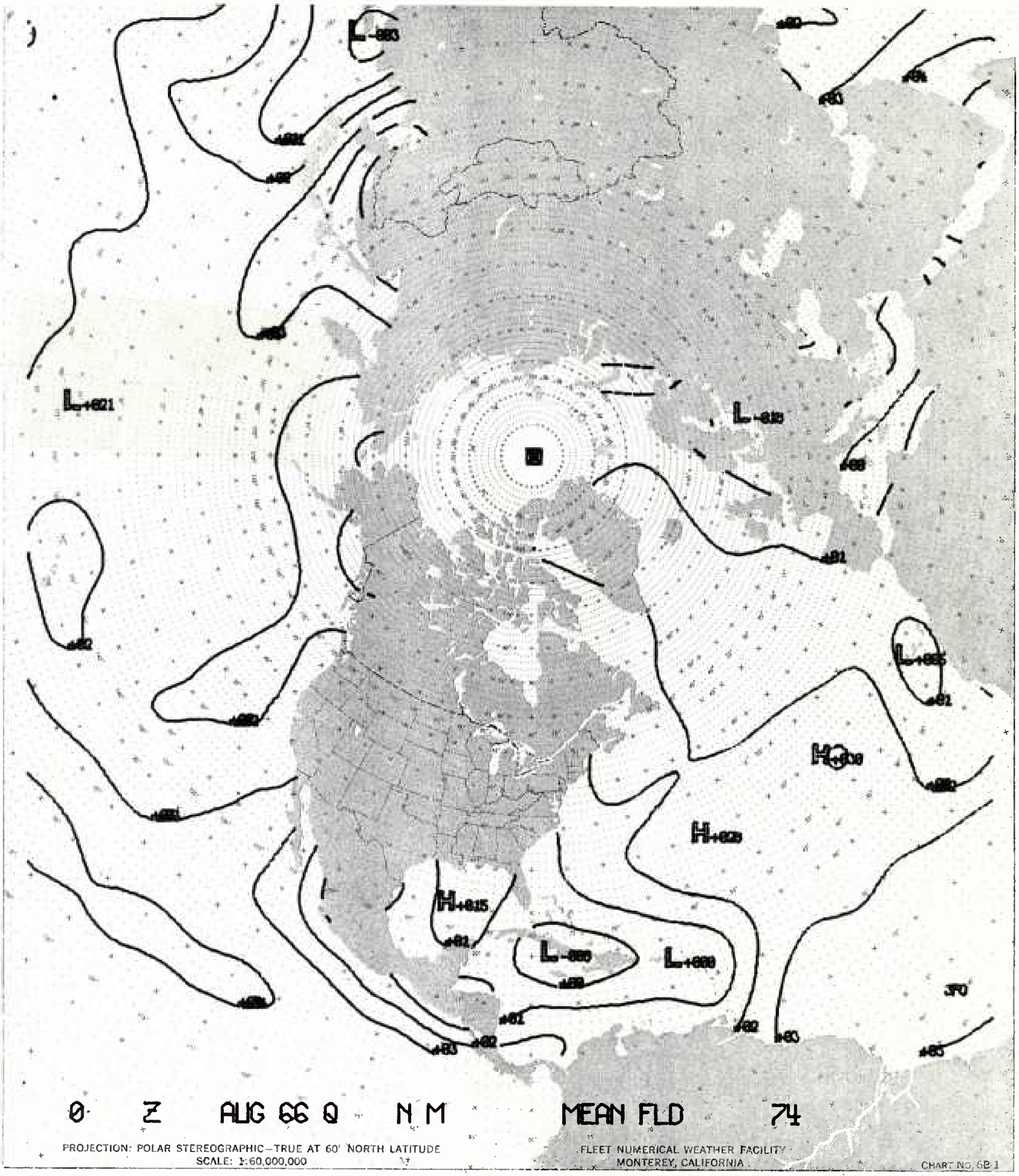
FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

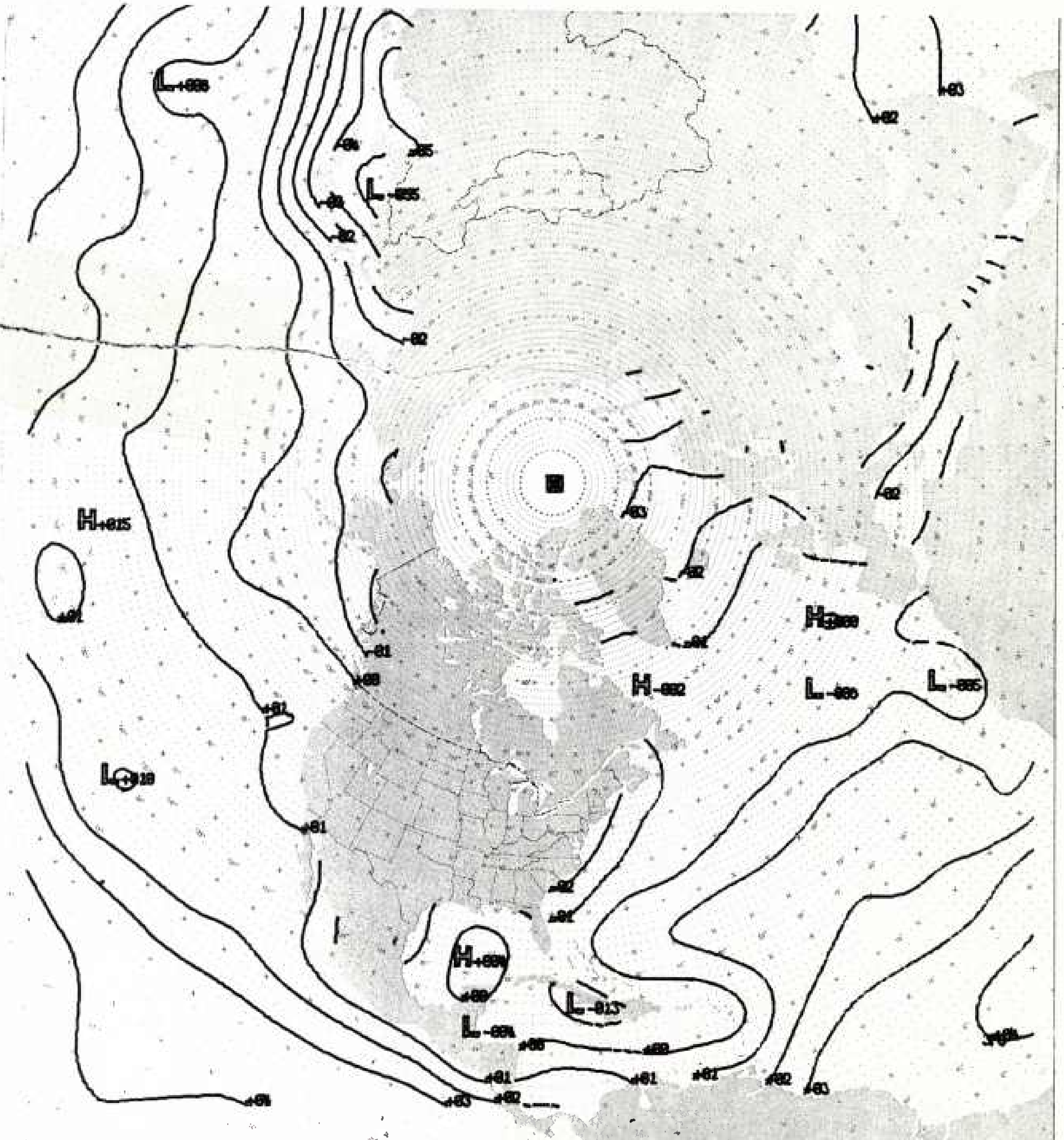


PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART No. 6B-1


L+821
L+815
H+830
H+825
H+815
L+865
0 Z AUG 66 0 N M MEAN FLD 74
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000
FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA
CHART NO. 6B-1

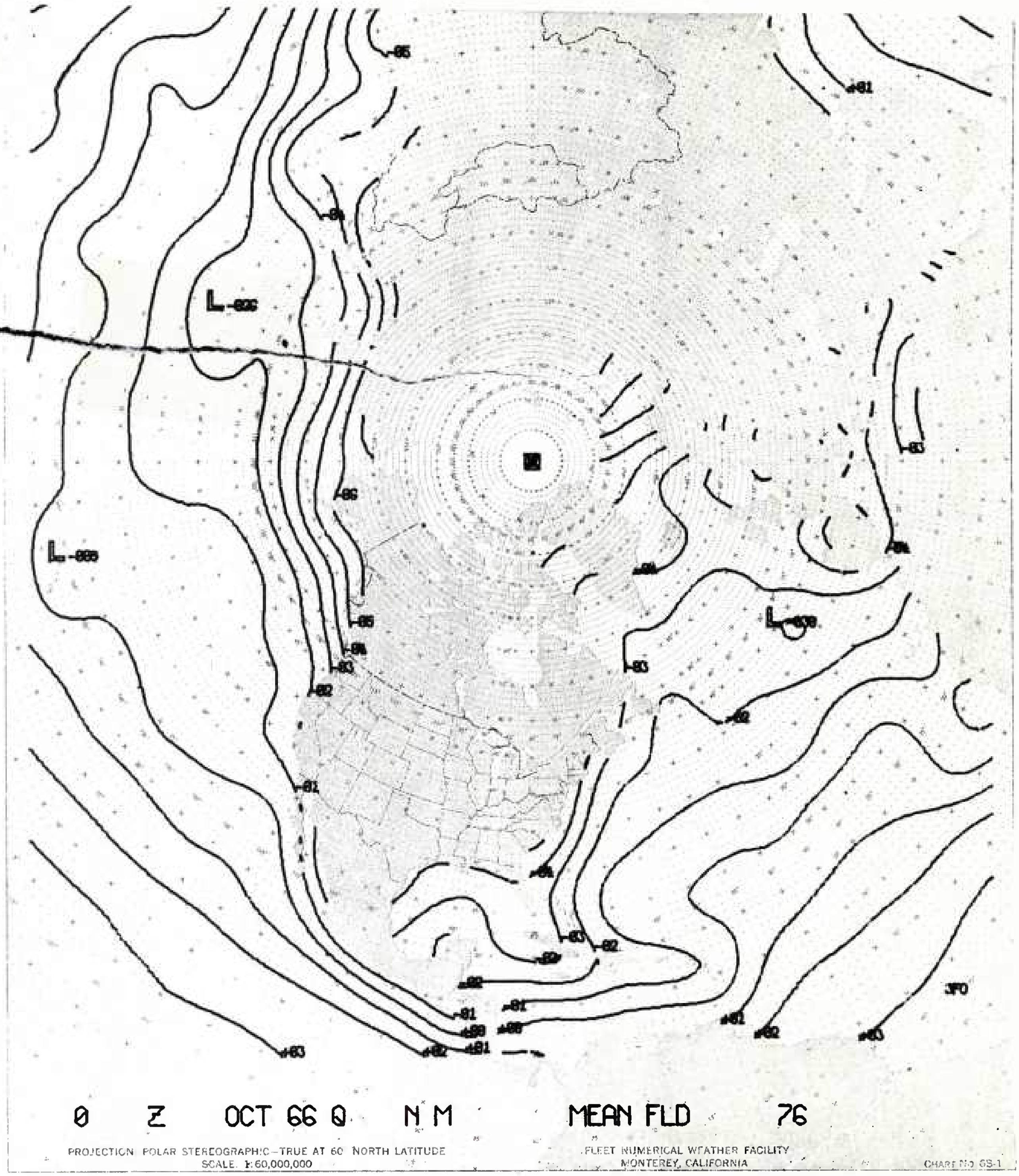


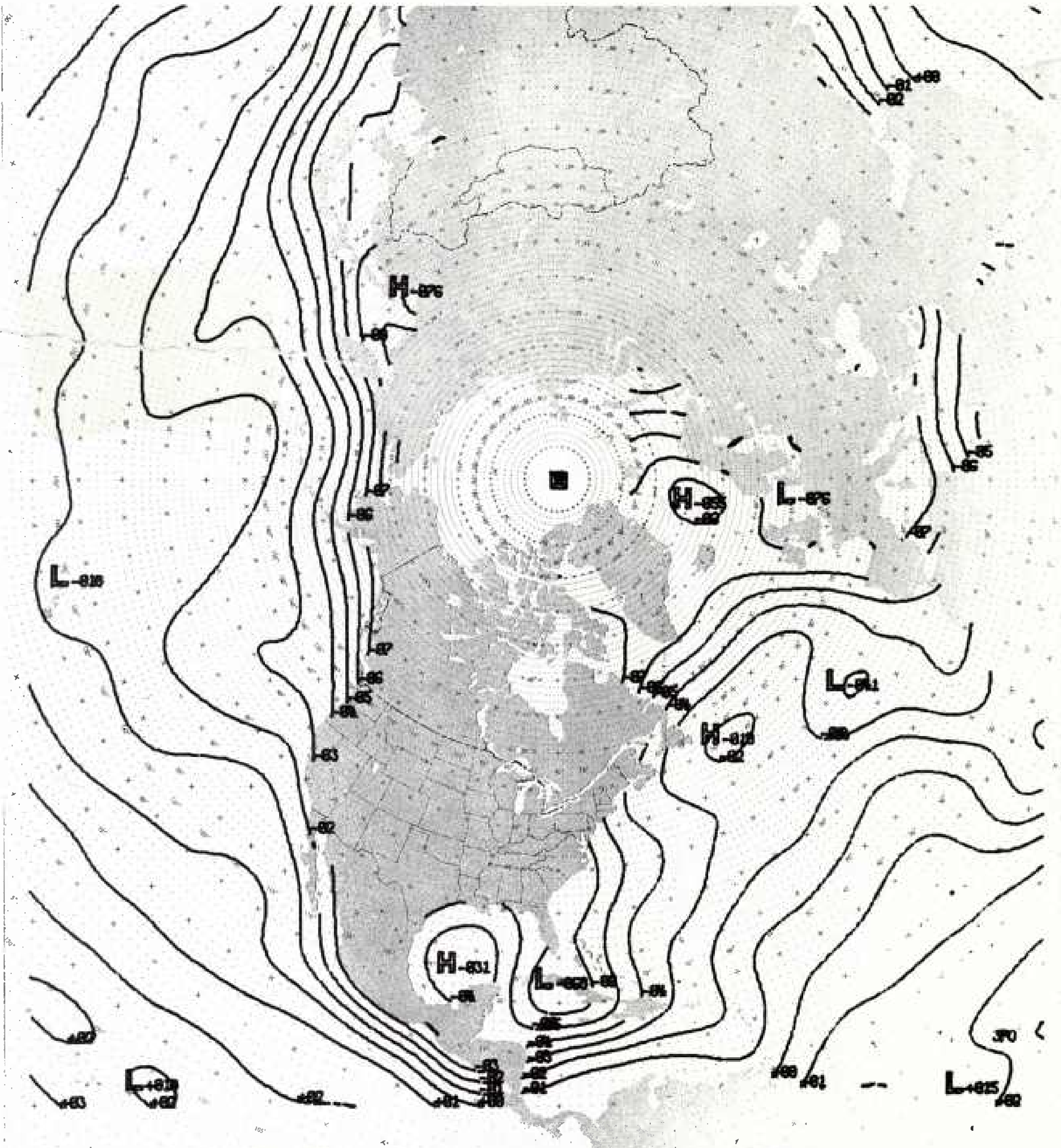
0 Z SEP 66 Q N M MEAN FLD 74

PROJECTION. POLAR STEREOGRAPHIC – TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART No. 6B-1

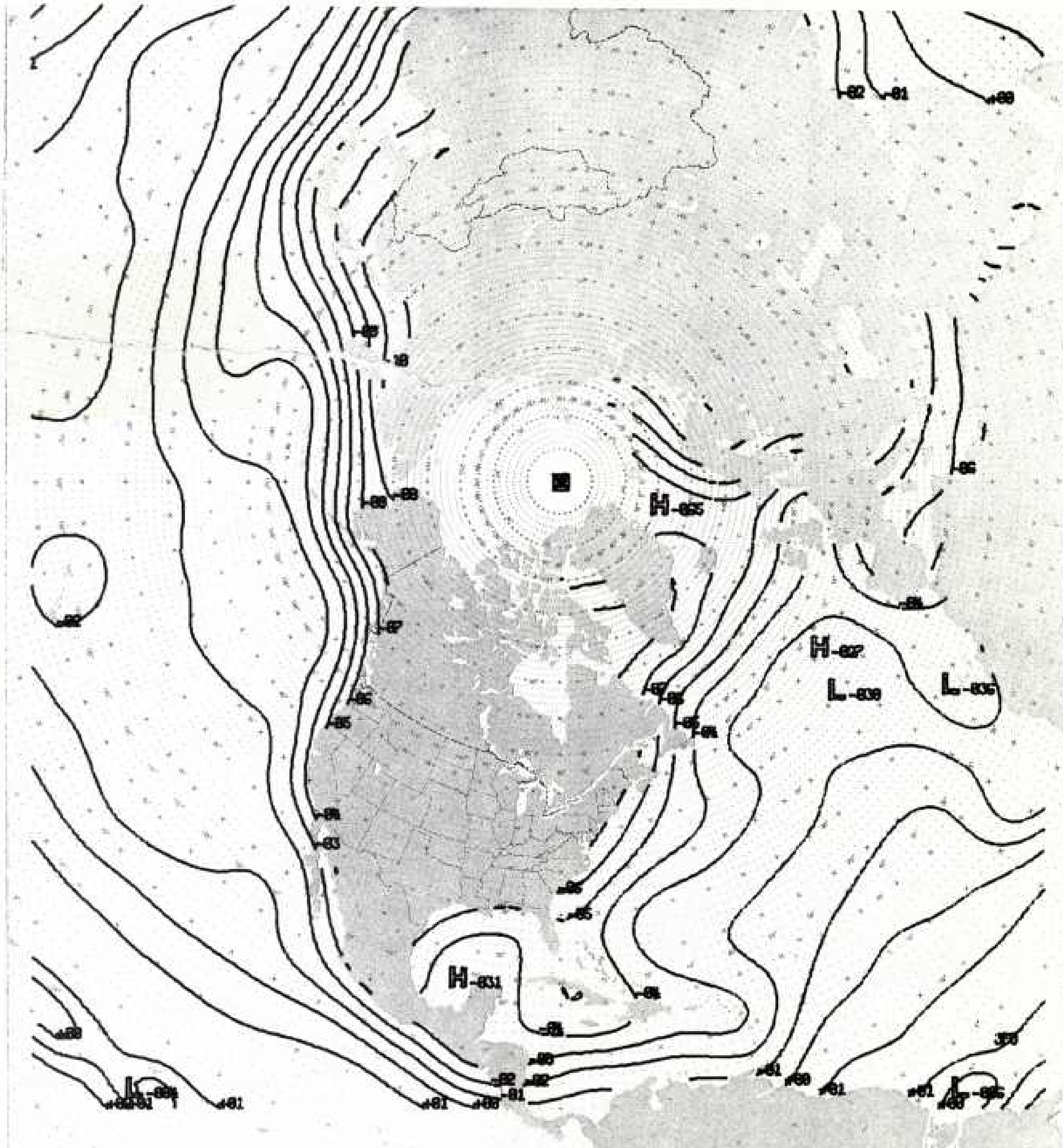

0 Z OCT 66 0 N M MEAN FLD 76
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE 1:60,000,000
FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA
CHART NO. GS-1



0 Z NOV 66 Q N M MEAN FLD 74

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

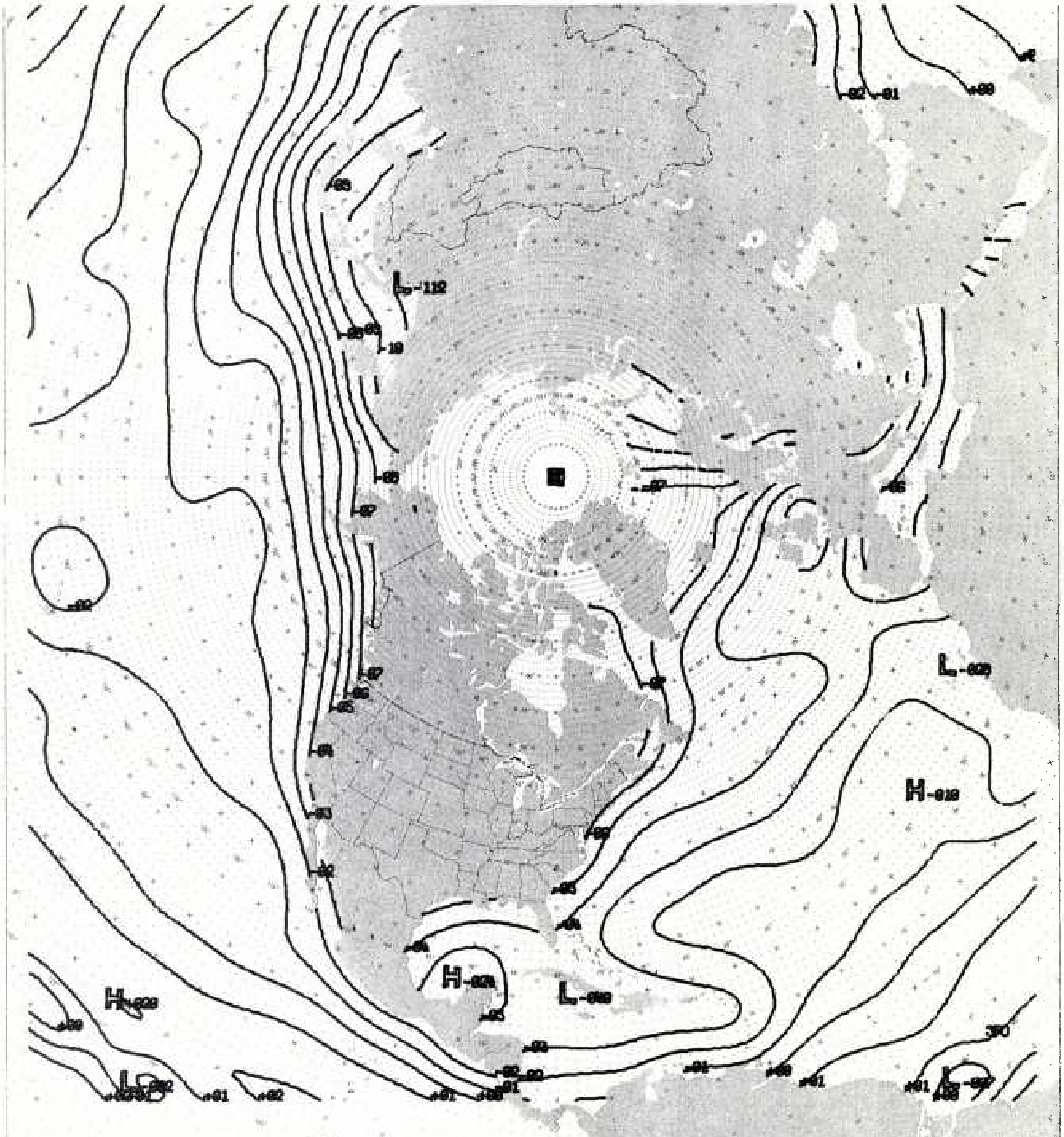


0 Z DEC 66 Q N M MEAN FLD 76

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART No. 6B

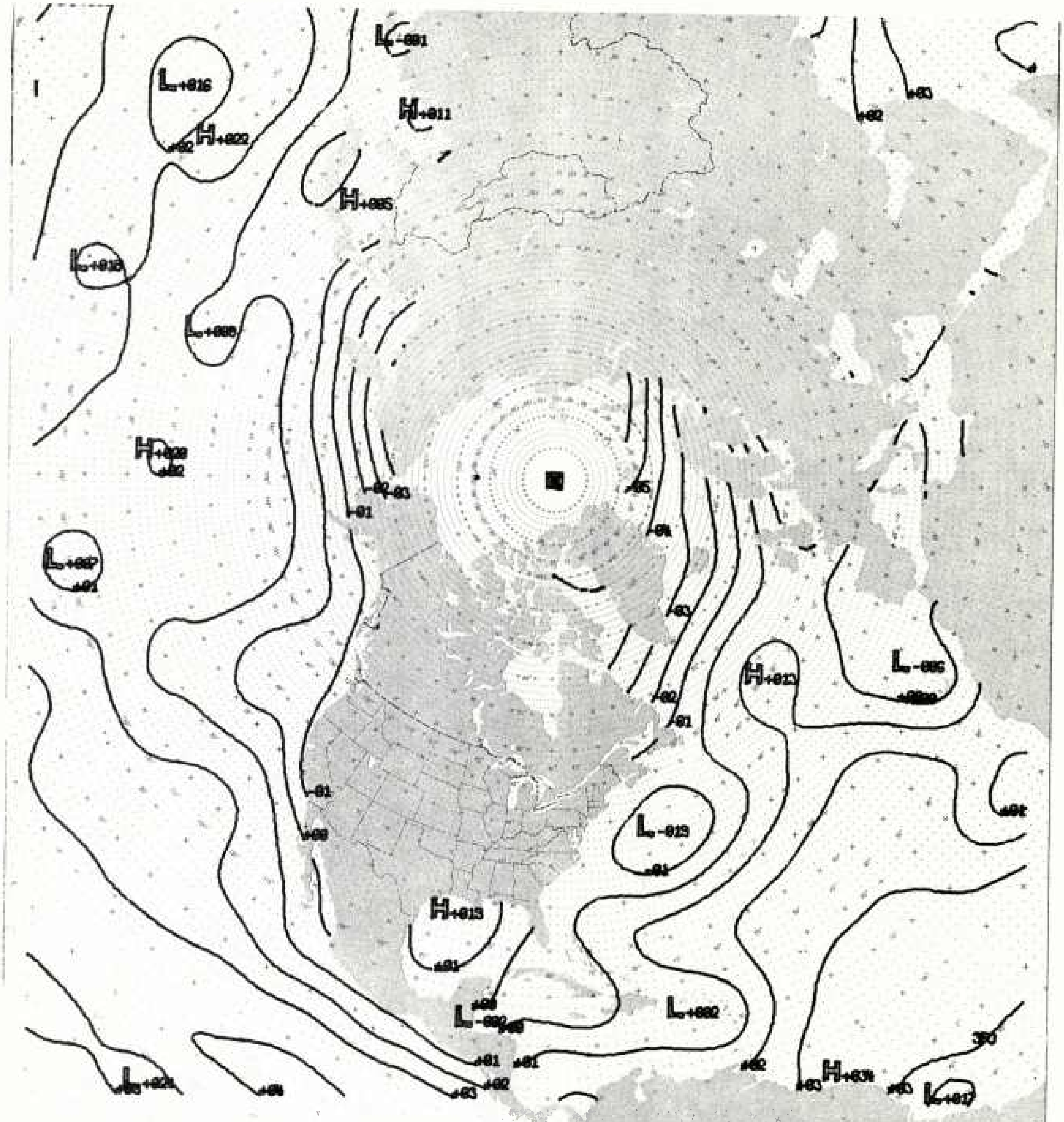


0 Z JAN 67 Q N M MEAN FLD 76

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART NO. 6B-1

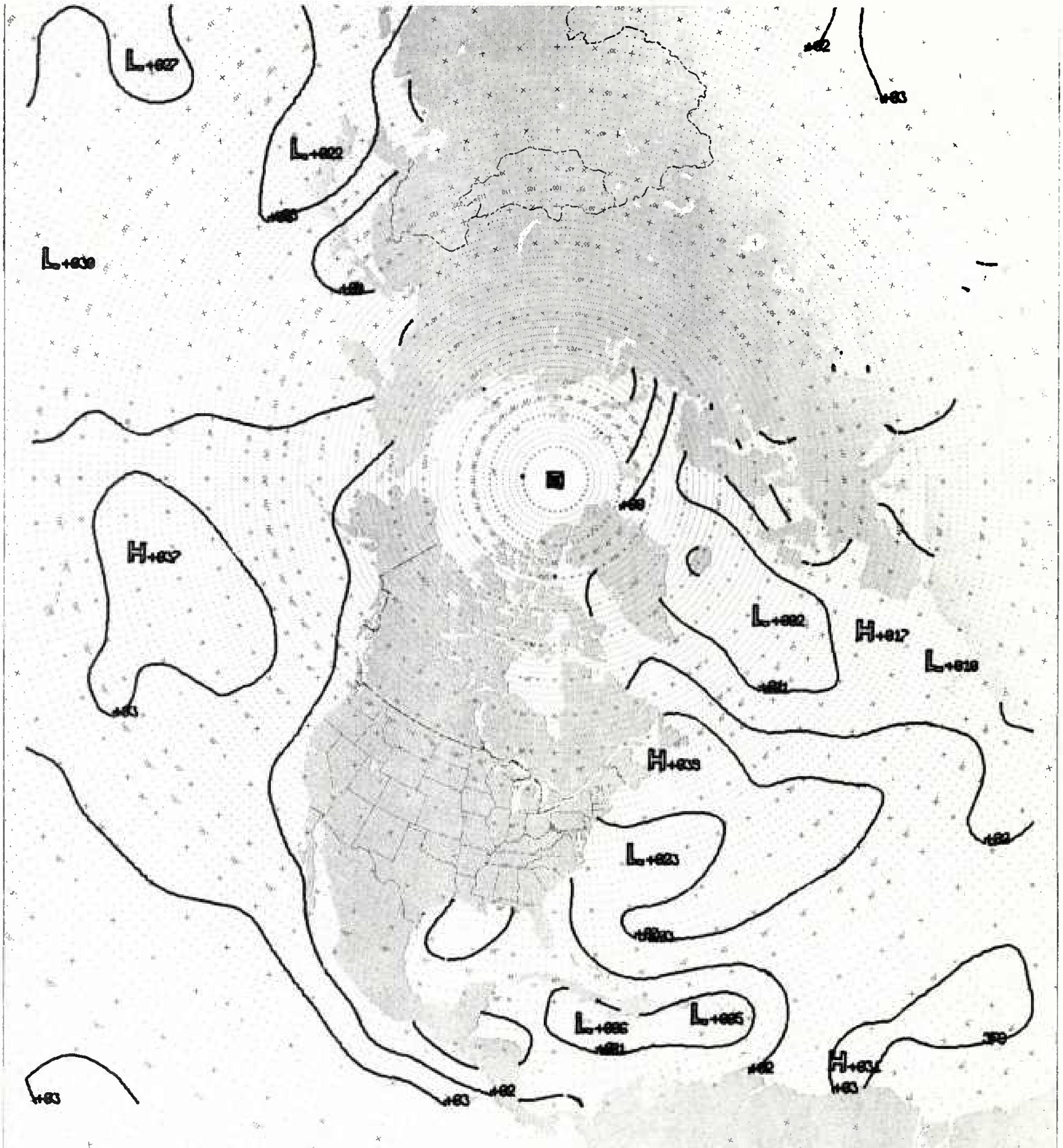


0 Z APR 67 Q N M MEAN FLD 74

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART No. 68 I

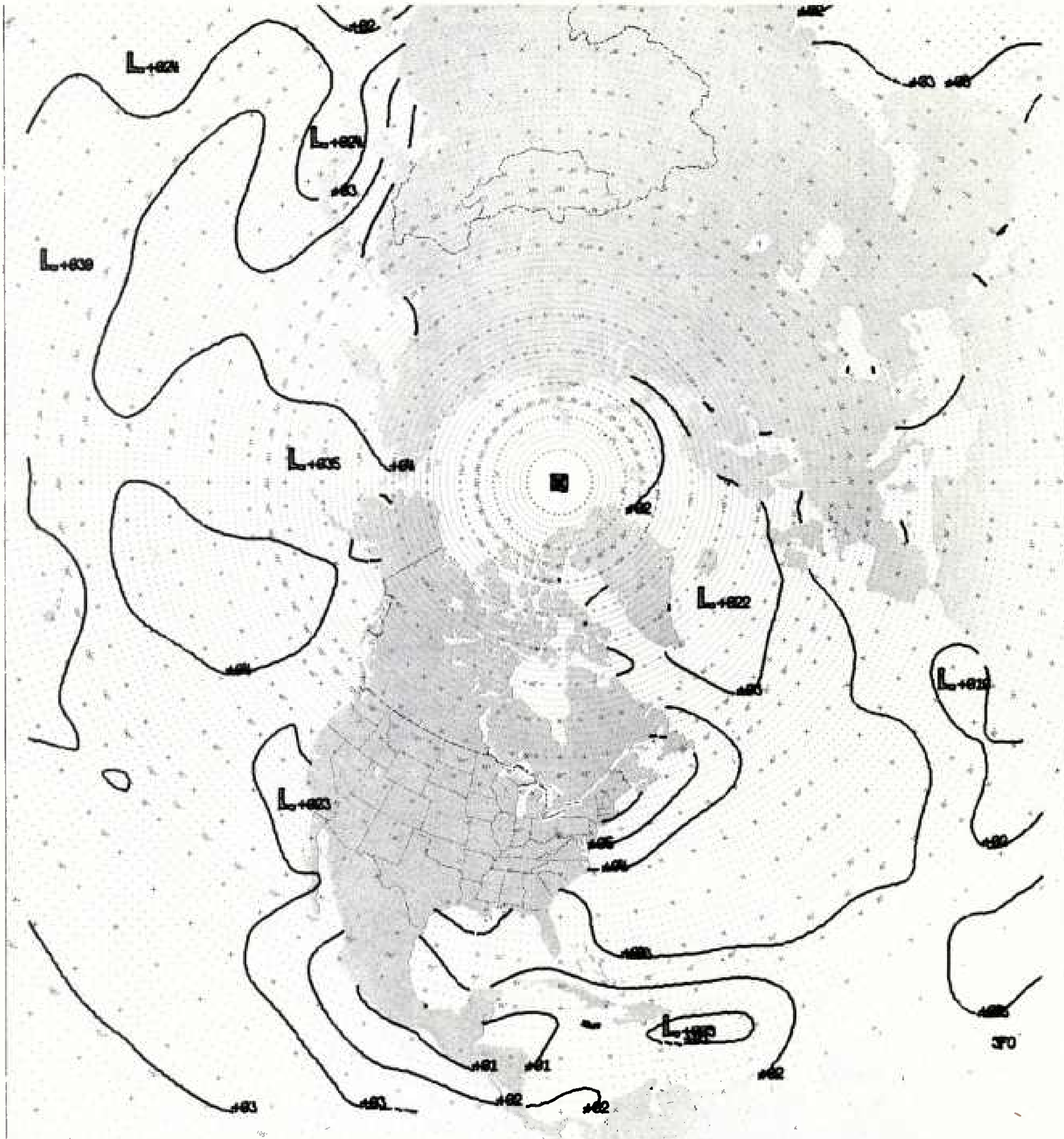


0 Z MAY 67 Q N M MEAN FLD 76

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

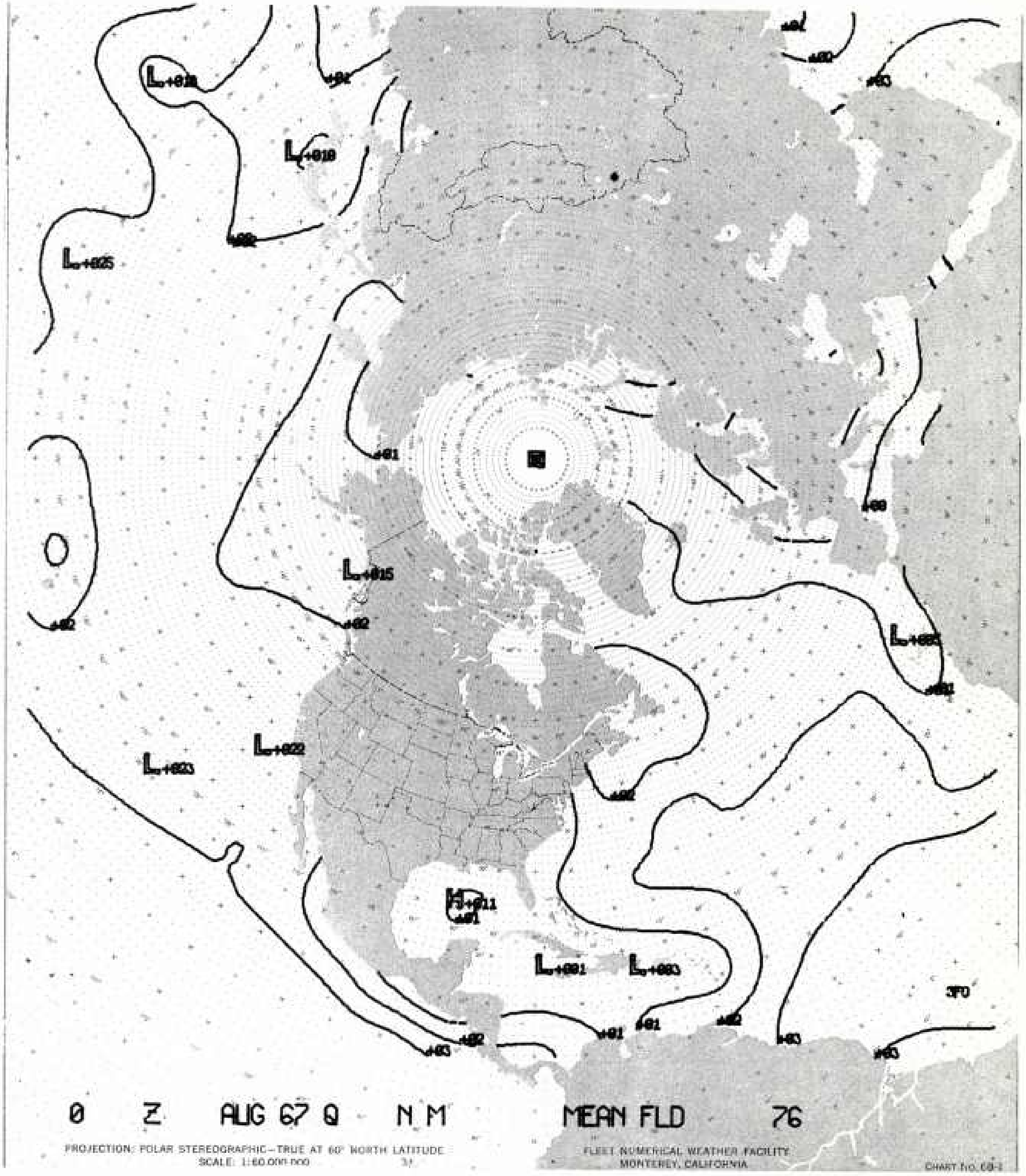
CHART No. 6B-1

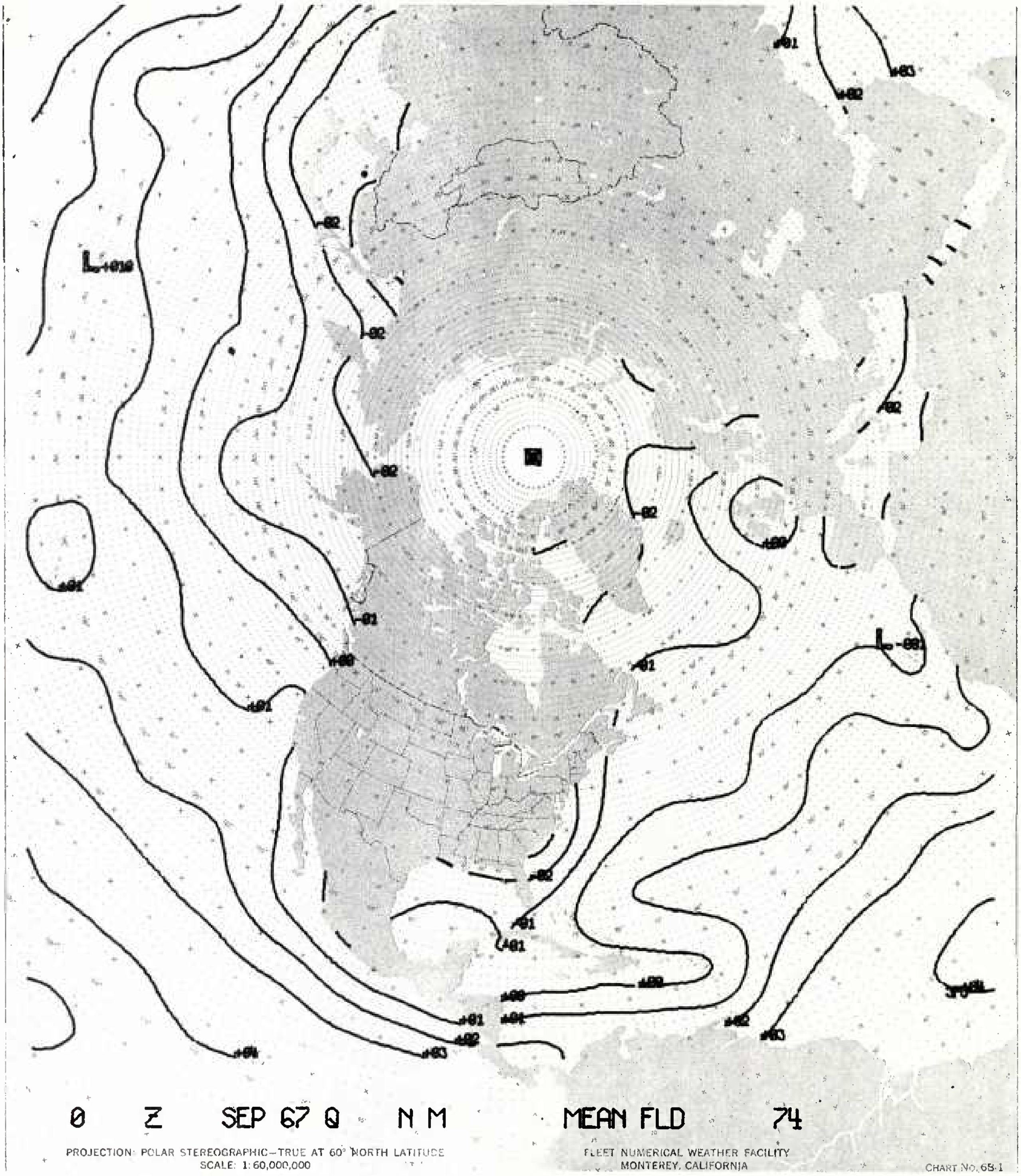


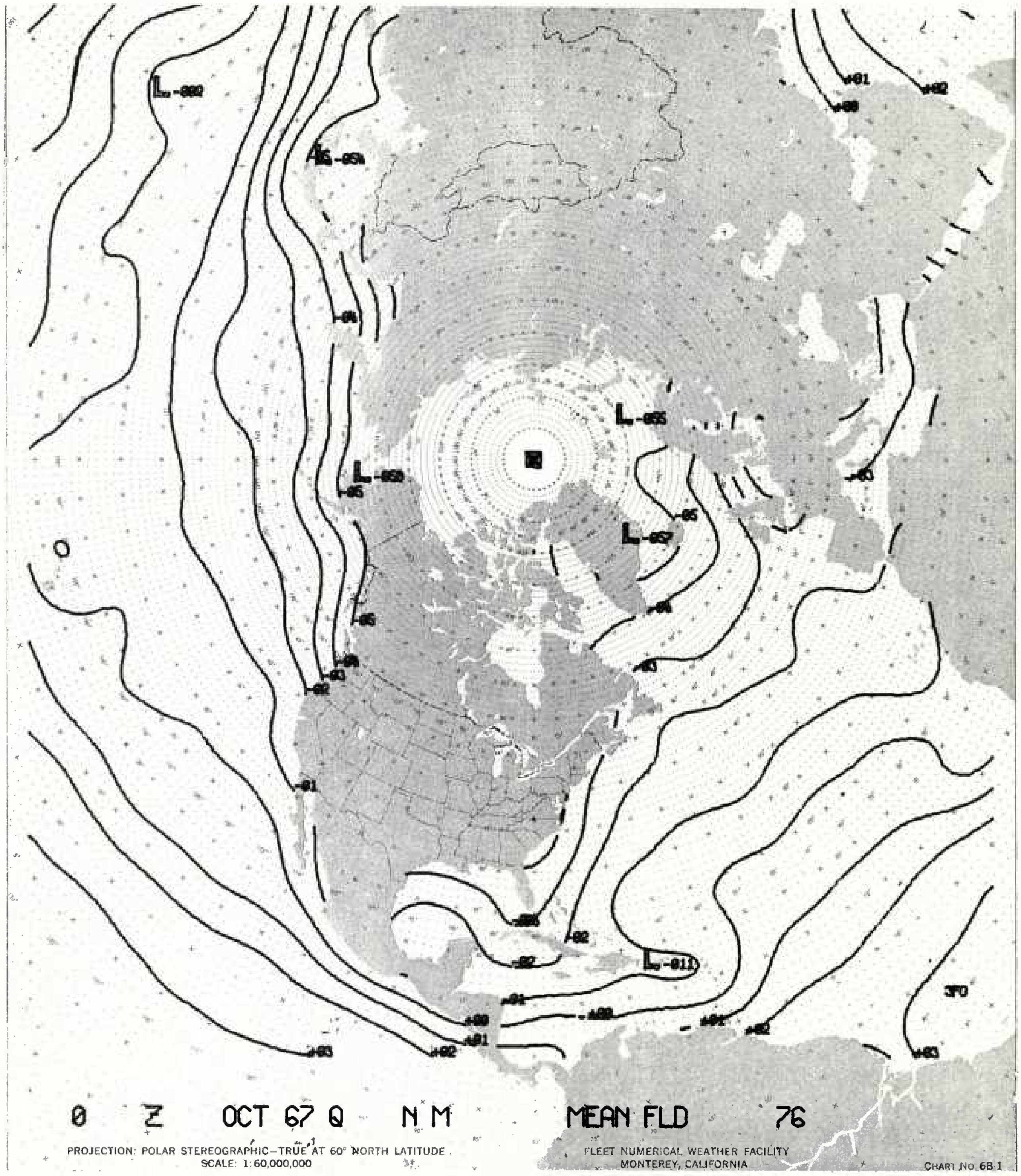
0 Z JUN 67 Q N M MEAN FLD 74

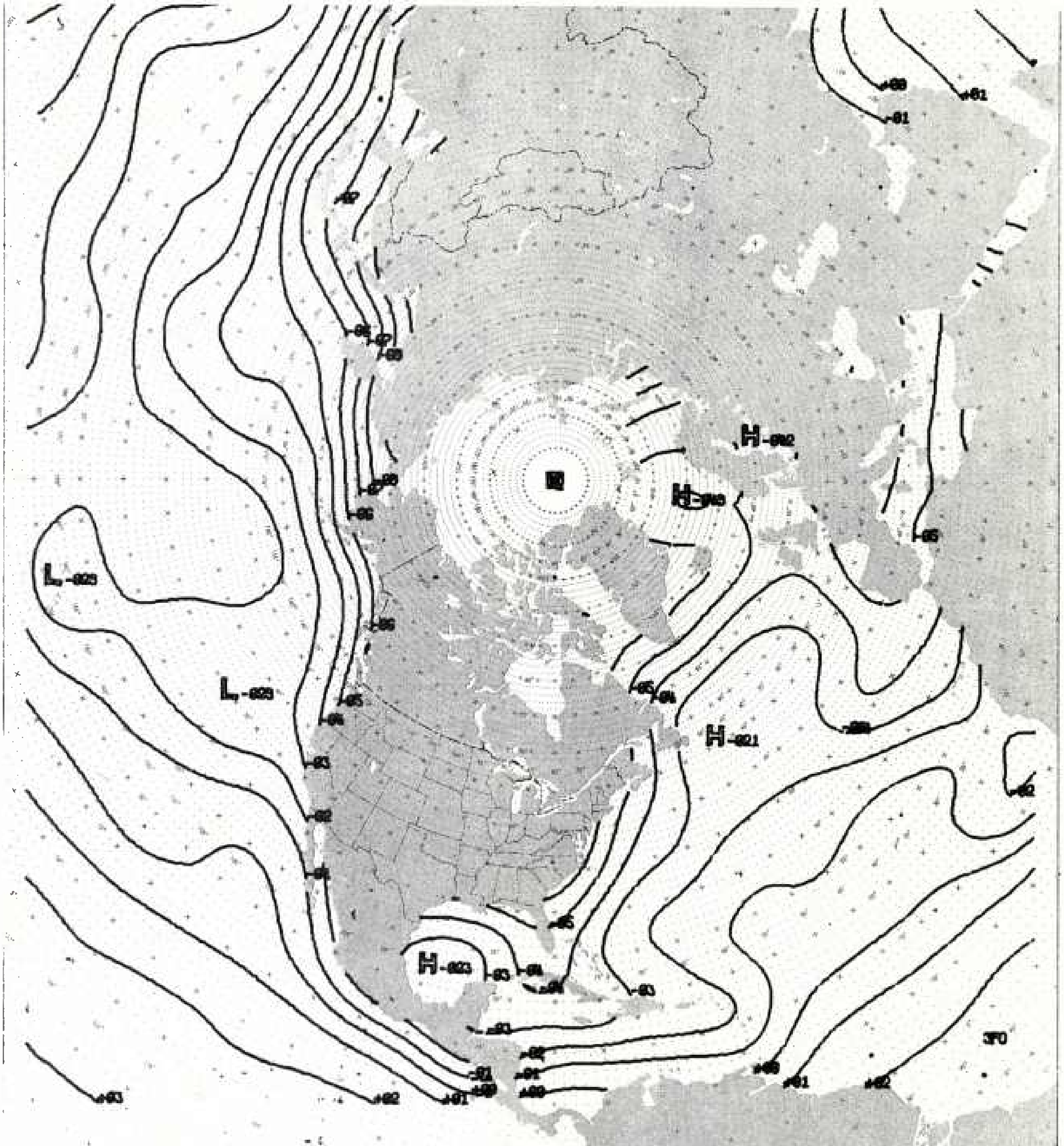
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA


0 Z AUG 67 Q N M
MEAN FLD 76
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000
FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA


0 Z SEP 67 Q N M MEAN FLD 74
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000
FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA
CHART No. 65-1


0 Z OCT 67 Q N M MEAN FLD 76
PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000
FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA
CHART No. 6B I

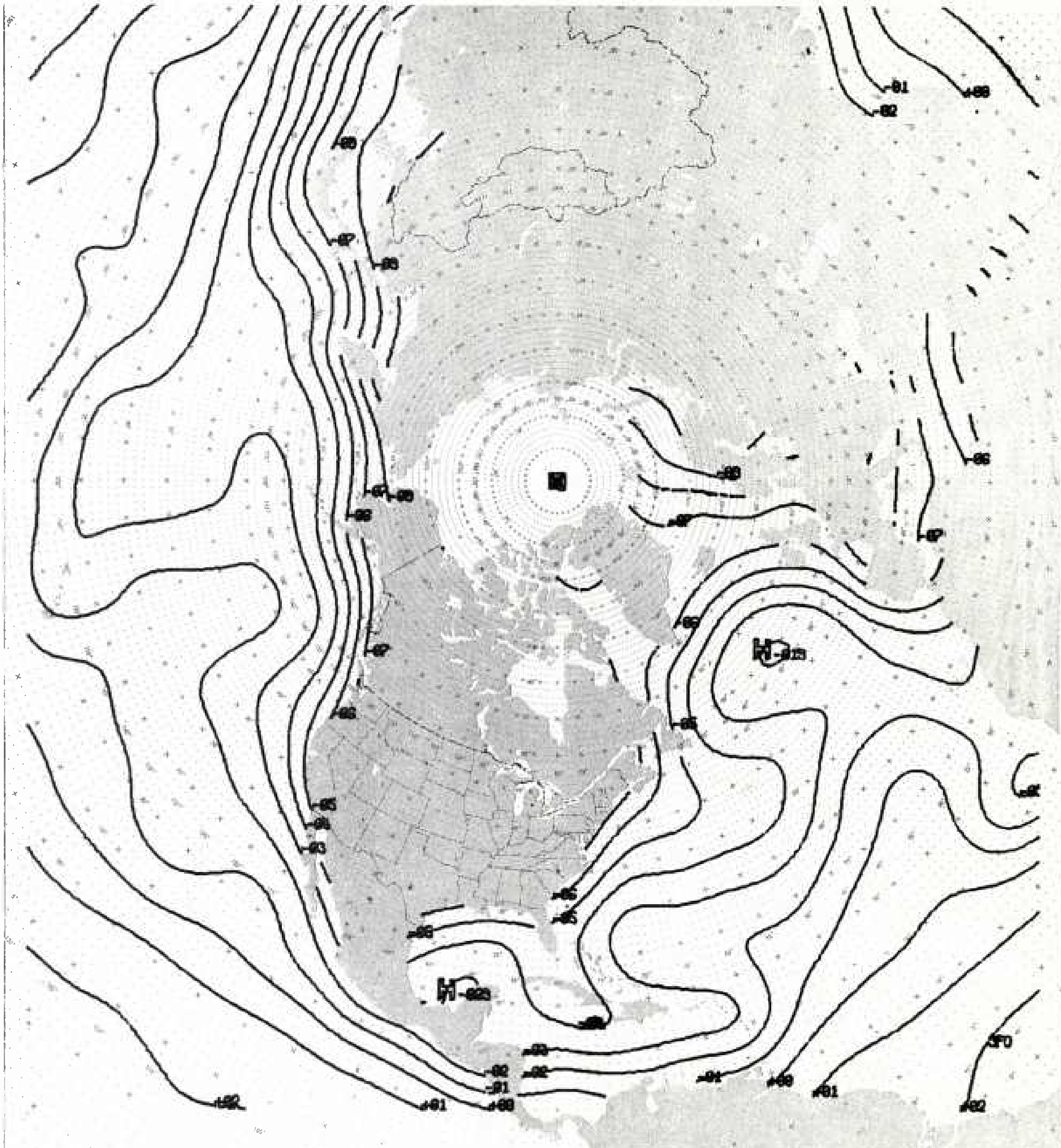


0 Z NOV 67 0 N M MEAN FLD 74

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART NO. 6B-1



0 Z DEC 67 Q N M MEAN FLD 74

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART NO. 6L

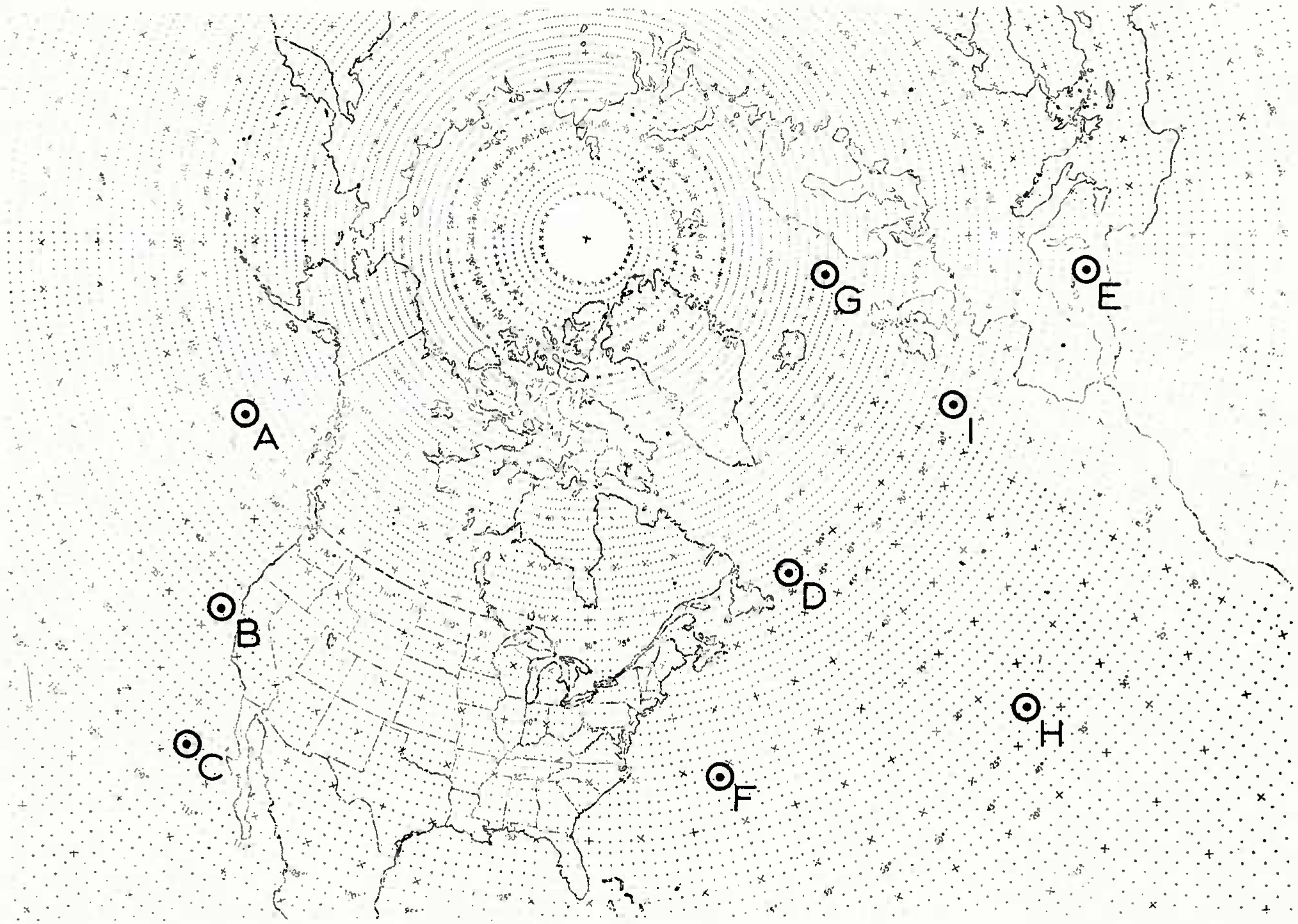


FIGURE 33 POSITIONS FOR WHICH MONTHLY MEAN SENSIBLE AND LATENT AND TOTAL HEAT EXCHANGE IN 1967 ARE GIVEN ON FIGURES 34 TO 39

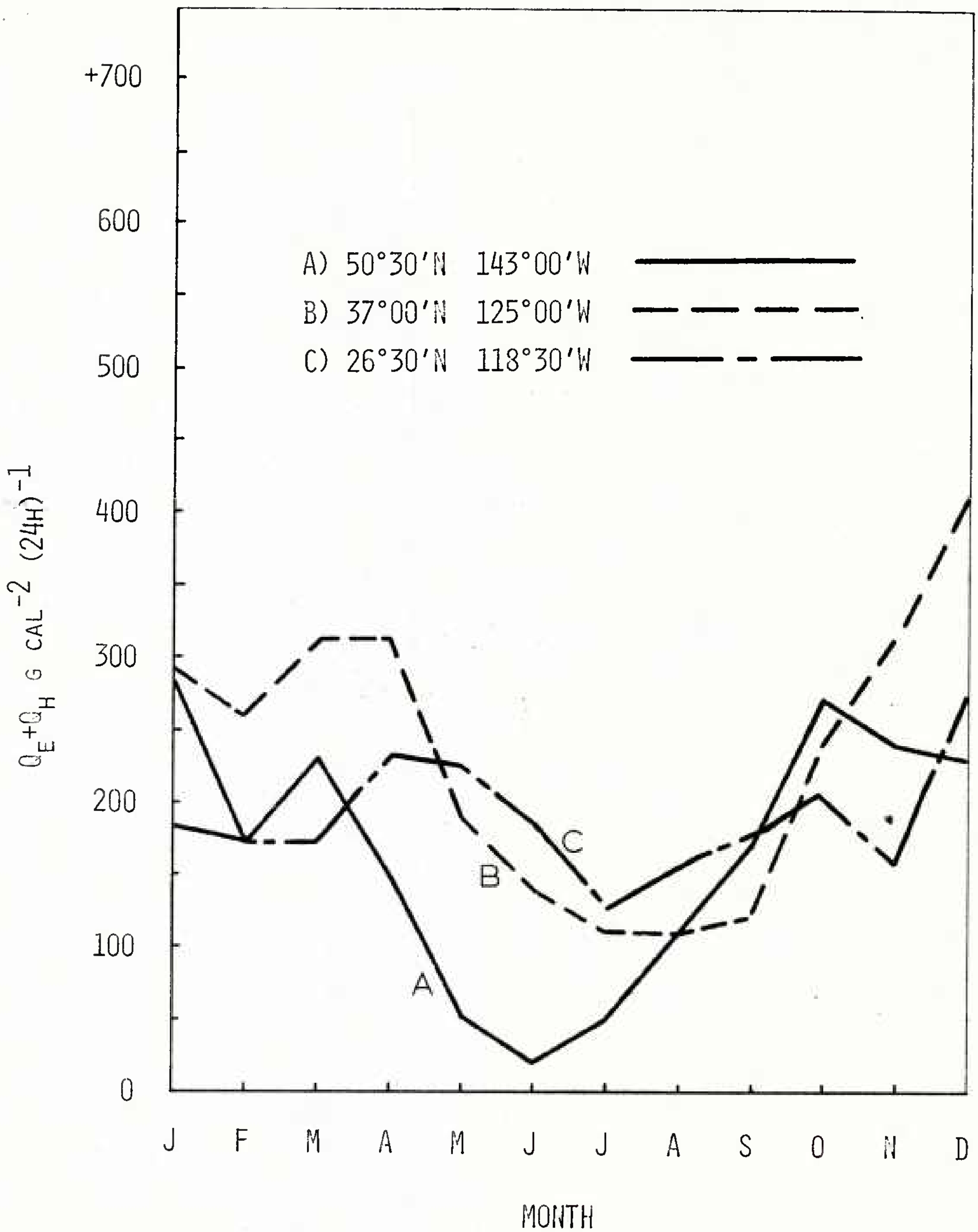


FIGURE 34 MONTHLY MEAN SENSIBLE AND LATENT HEAT EXCHANGE AT THREE LOCATIONS OFF WEST COAST OF NORTH AMERICA IN 1967

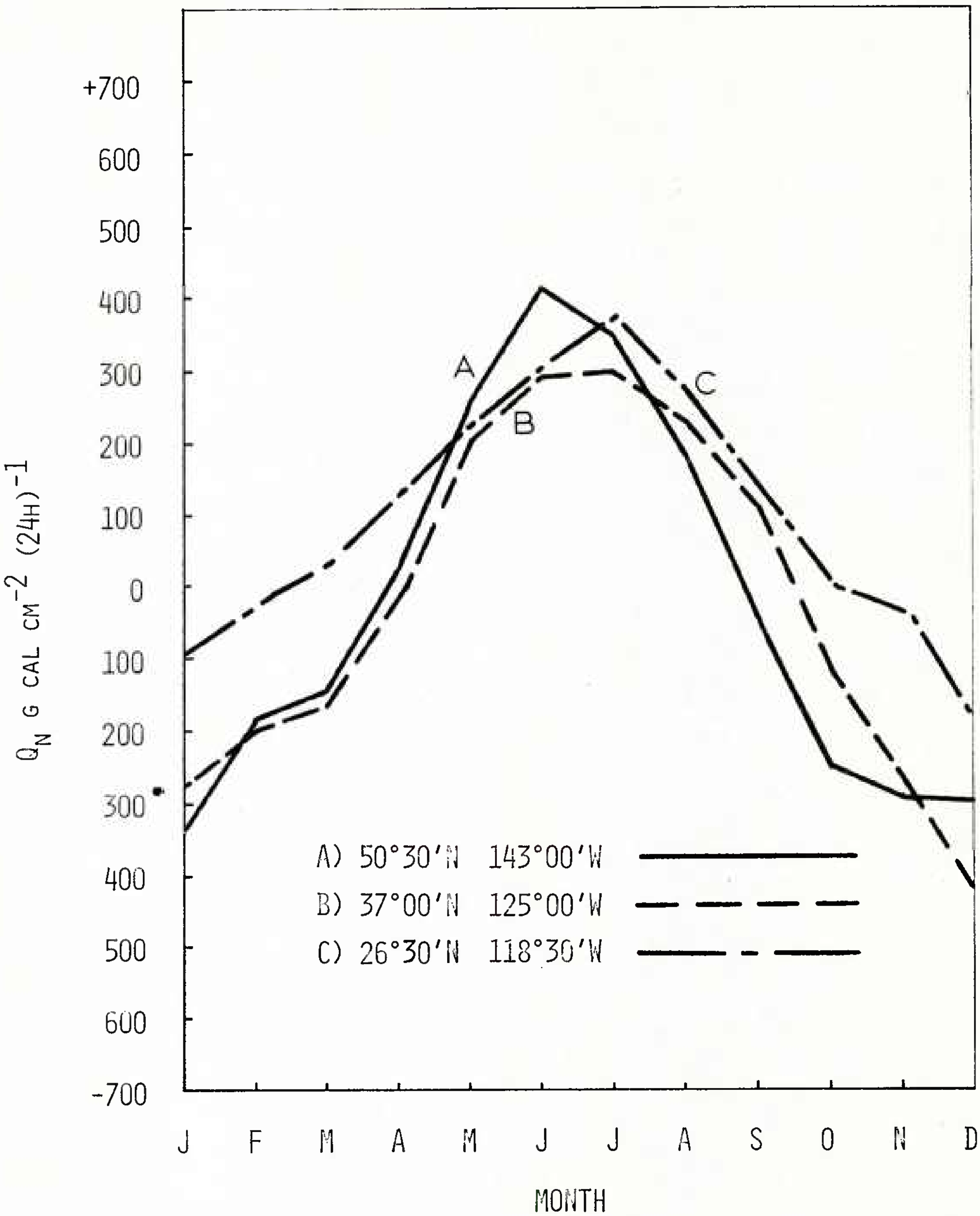


FIGURE 35 MONTHLY MEAN TOTAL HEAT EXCHANGE AT THREE LOCATIONS OFF WEST COAST OF MORTH AMERICA IN 1967

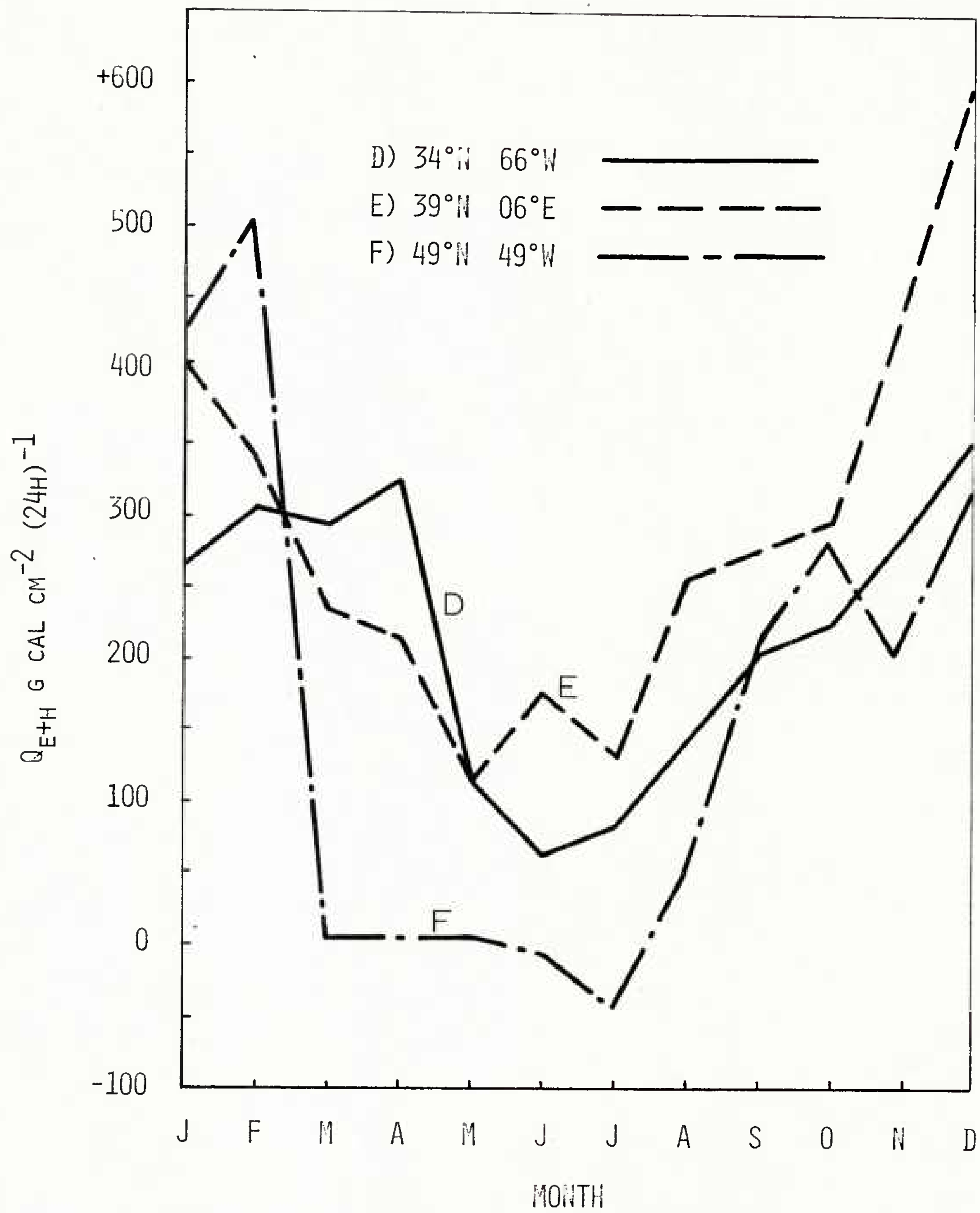


FIGURE 36 MONTHLY MEAN SENSIBLE AND LATENT HEAT EXCHANGE AT TWO LOCATATIONS OFF EAST COAST OF MORTH AMERICA AND AT ONE LOCATION IN EASTERN MEDITERRANEAN IN 1967

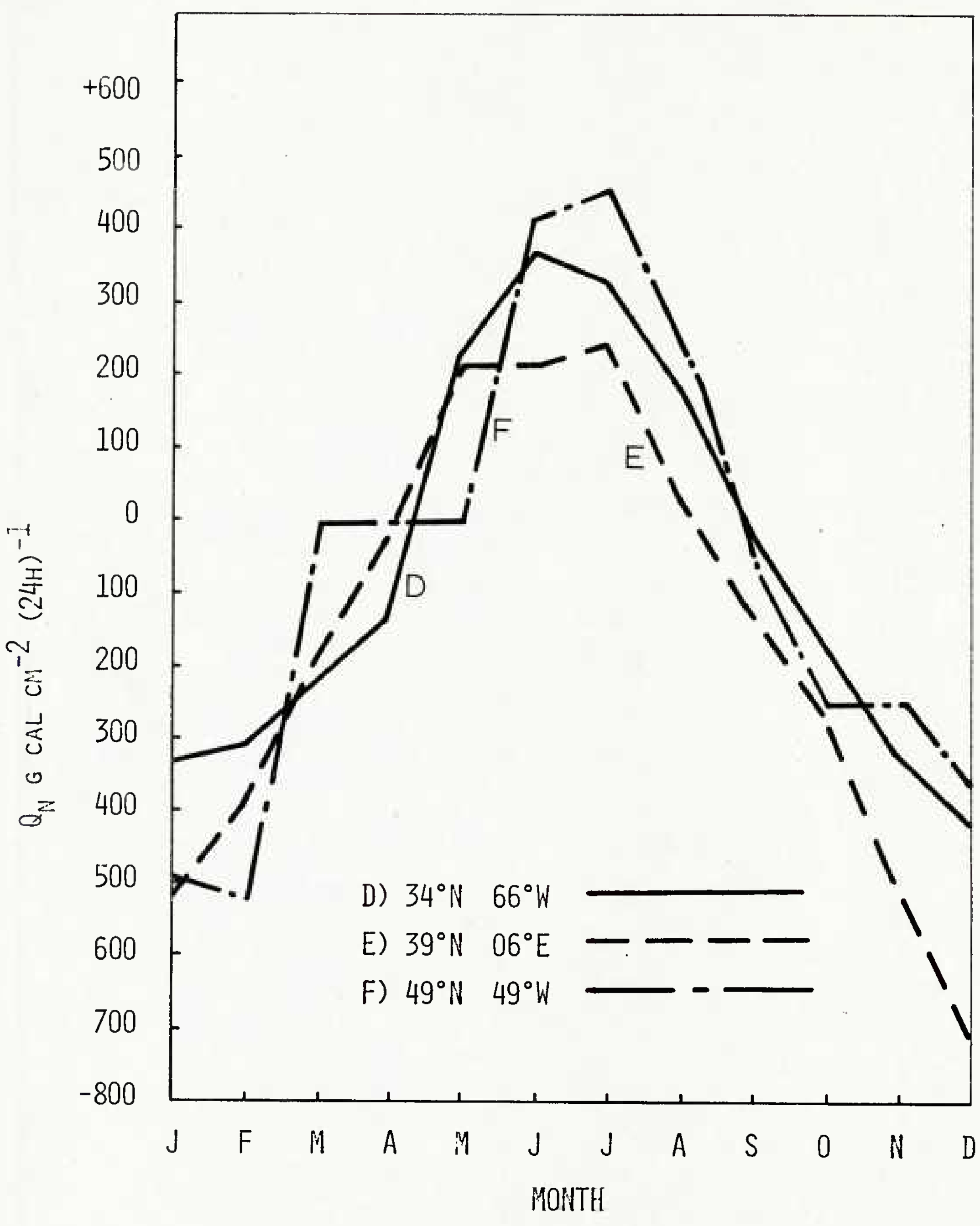


FIGURE 37 MONTHLY MEAN TOTAL HEAT EXCHANGE AT TWO LOCATIONS OFF EAST COAST OF NORTH AMERICA AND AT ONE LOCATION IN EASTERN MEDITERRANEAN IN 1967

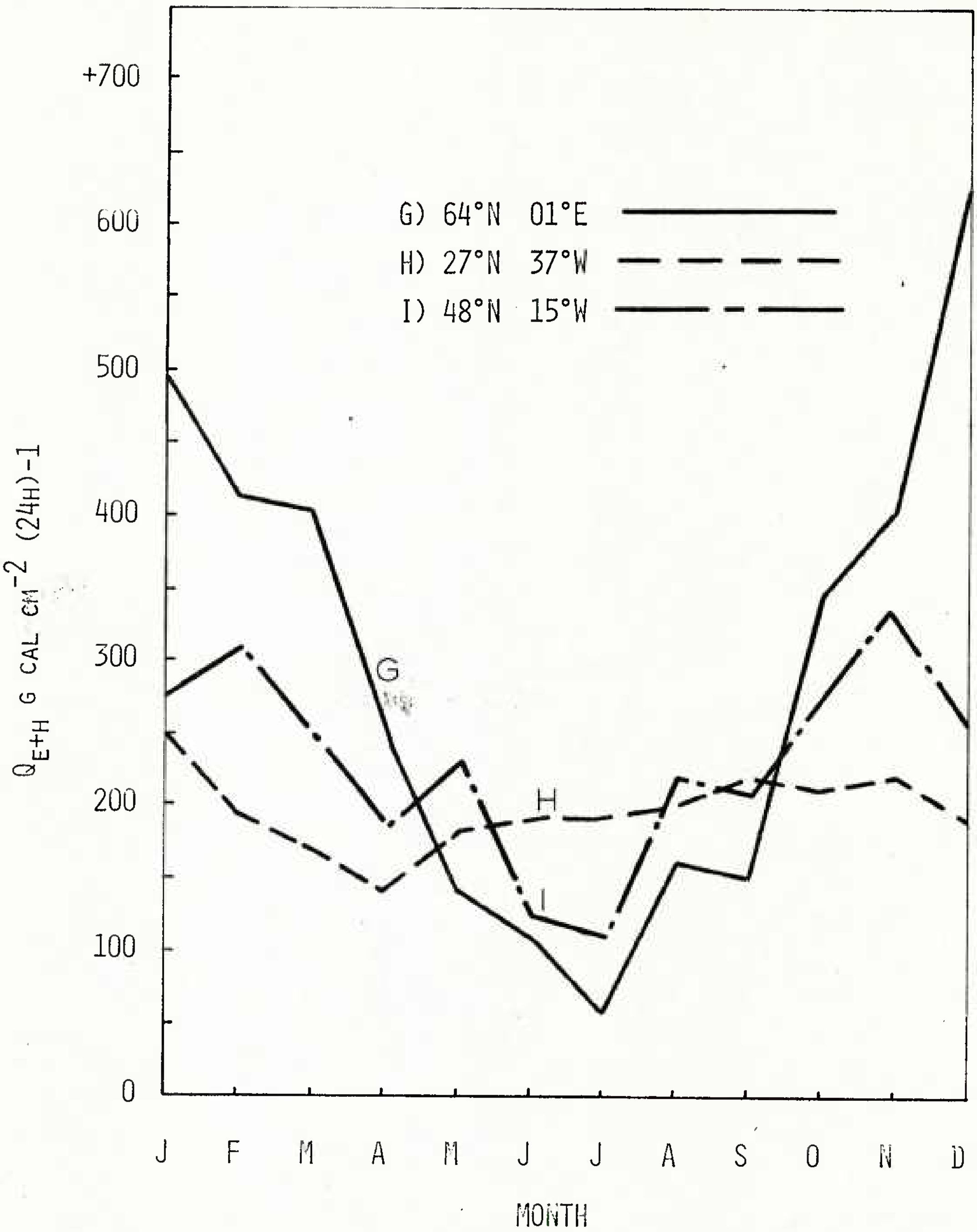


FIGURE 38 MONTHLY MEAN SENSIBLE AND LATENT HEAT EXCHANGE AT TWO LOCATIONS IN EASTERN NORTH ATLANTIC AND AT ONE LOCATION IN CENTRAL ATLANTIC IN 1967

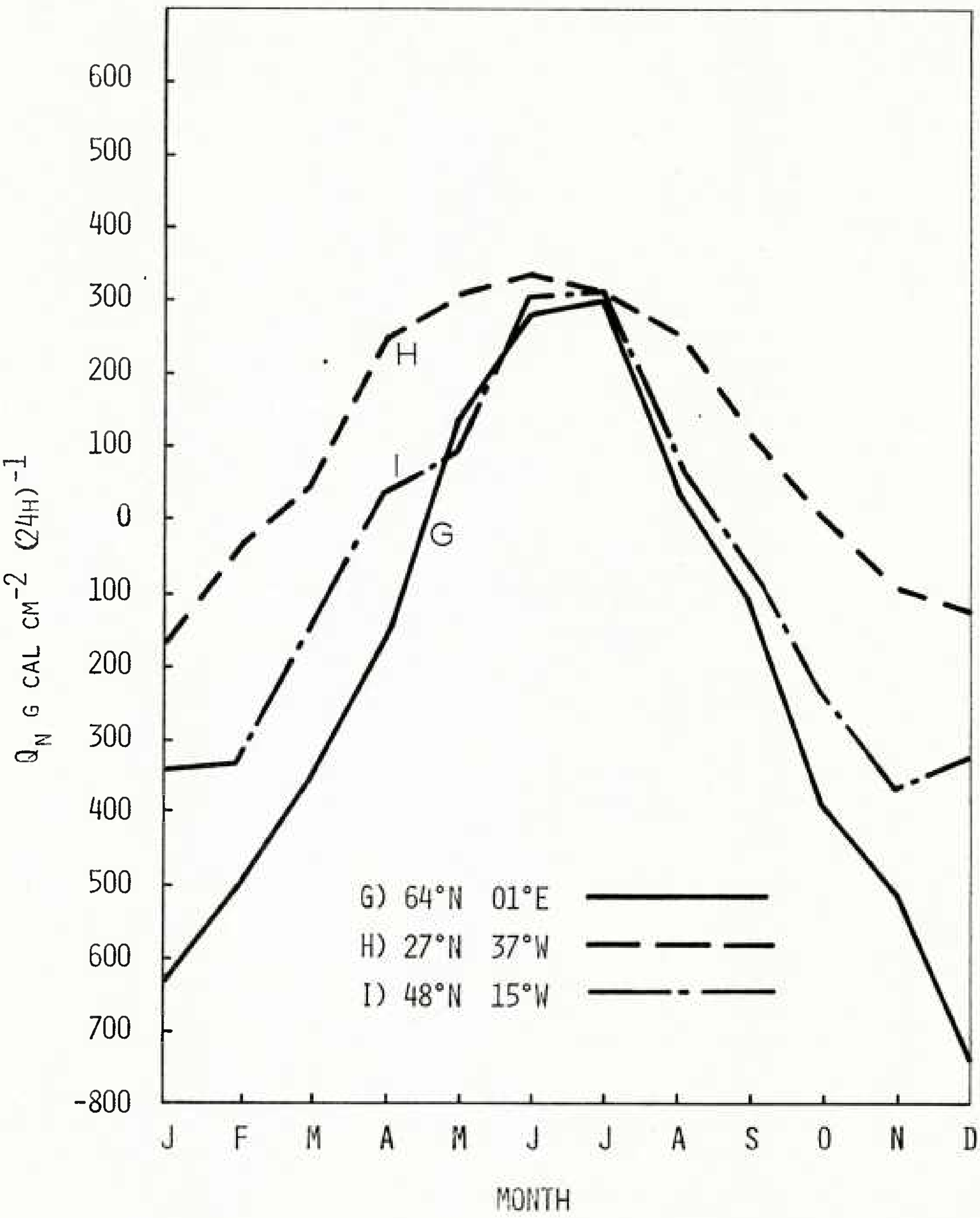


Figure 39 Monthly mean total heat exchange at two locations in eastern North Atlantic and at one location in central Atlantic in 1967

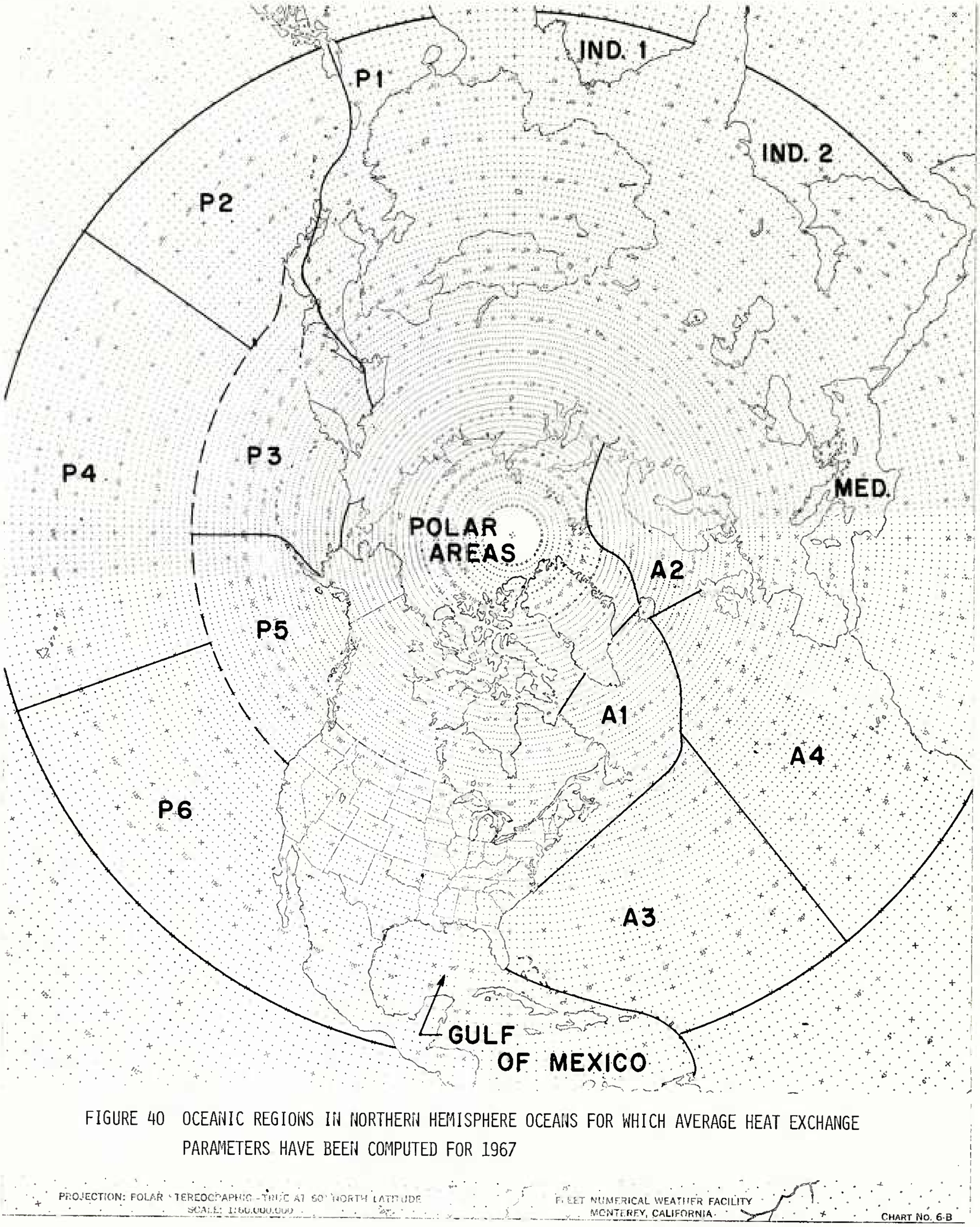


FIGURE 40 OCEANIC REGIONS IN NORTHERN HEMISPHERE OCEANS FOR WHICH AVERAGE HEAT EXCHANGE PARAMETERS HAVE BEEN COMPUTED FOR 1967

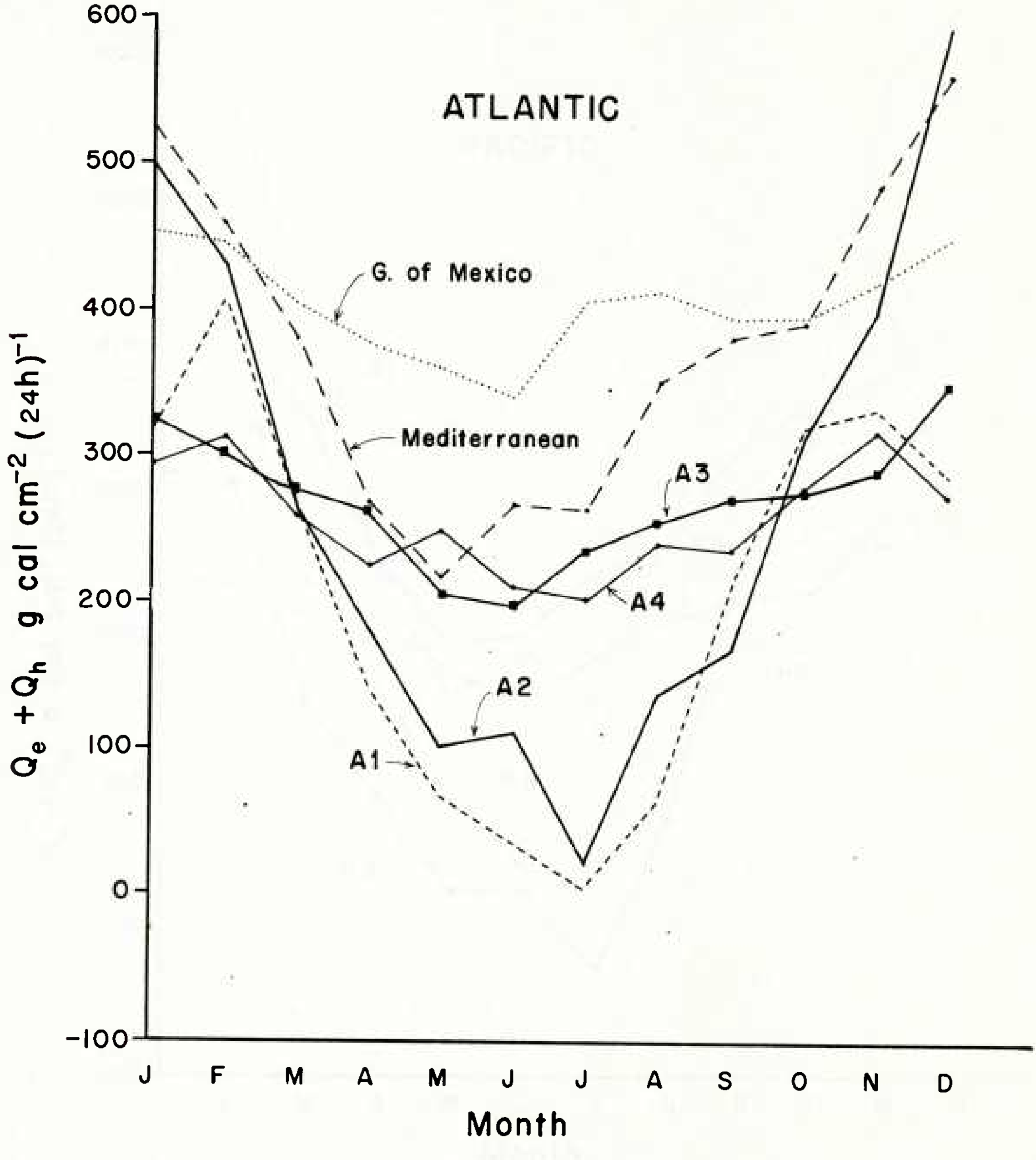


FIGURE 41 MONTHLY MEAN SENSIBLE AND LATENT HEAT EXCHANGE IN THE OCEANIC REGIONS IN NORTH ATLANTIC OCEAN IN 1967

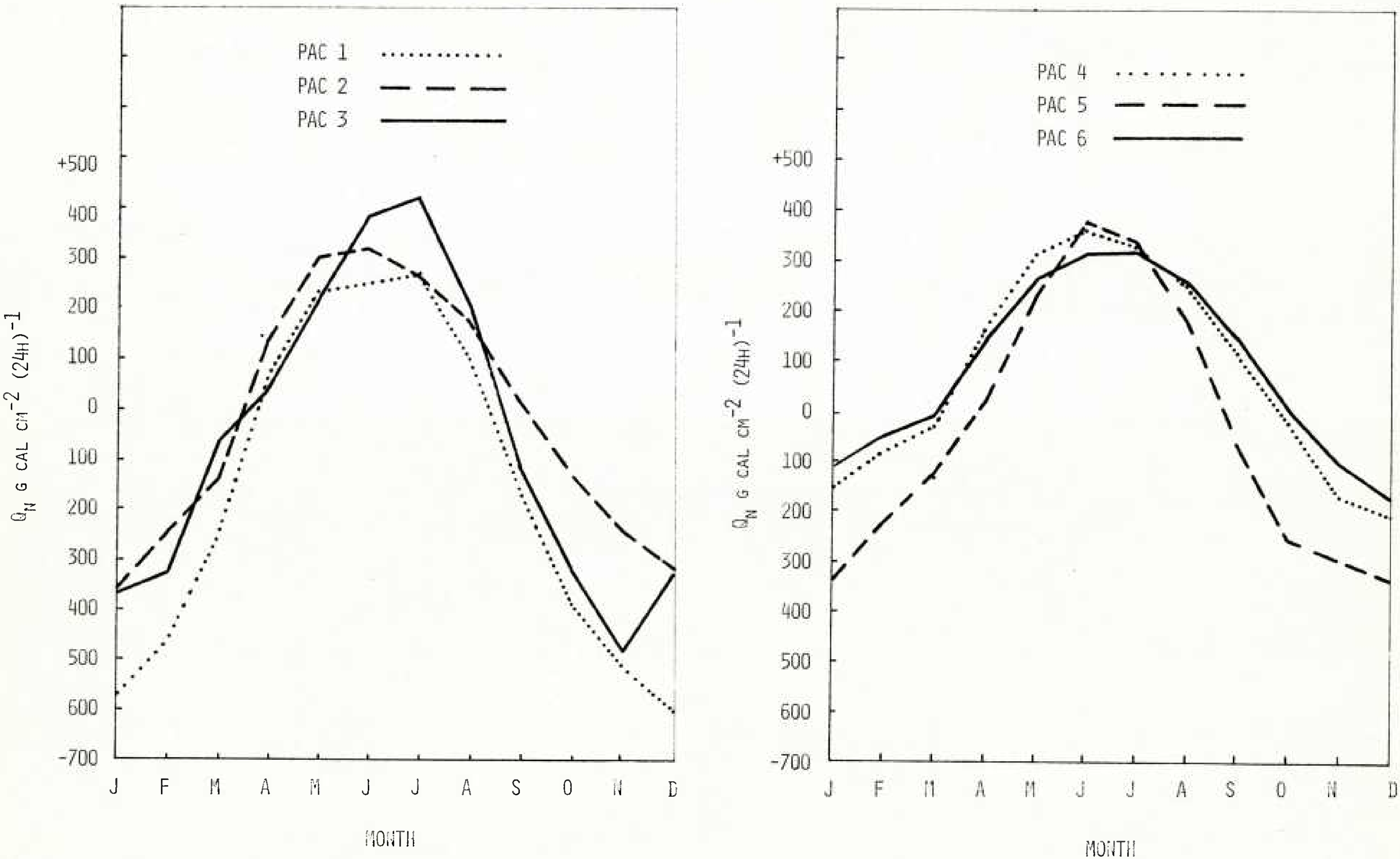


FIGURE 43 MONTHLY MEAN TOTAL HEAT EXCHANGE IN THE OCEANIC REGIONS IN NORTH ATLANTIC OCEAN IN 1967

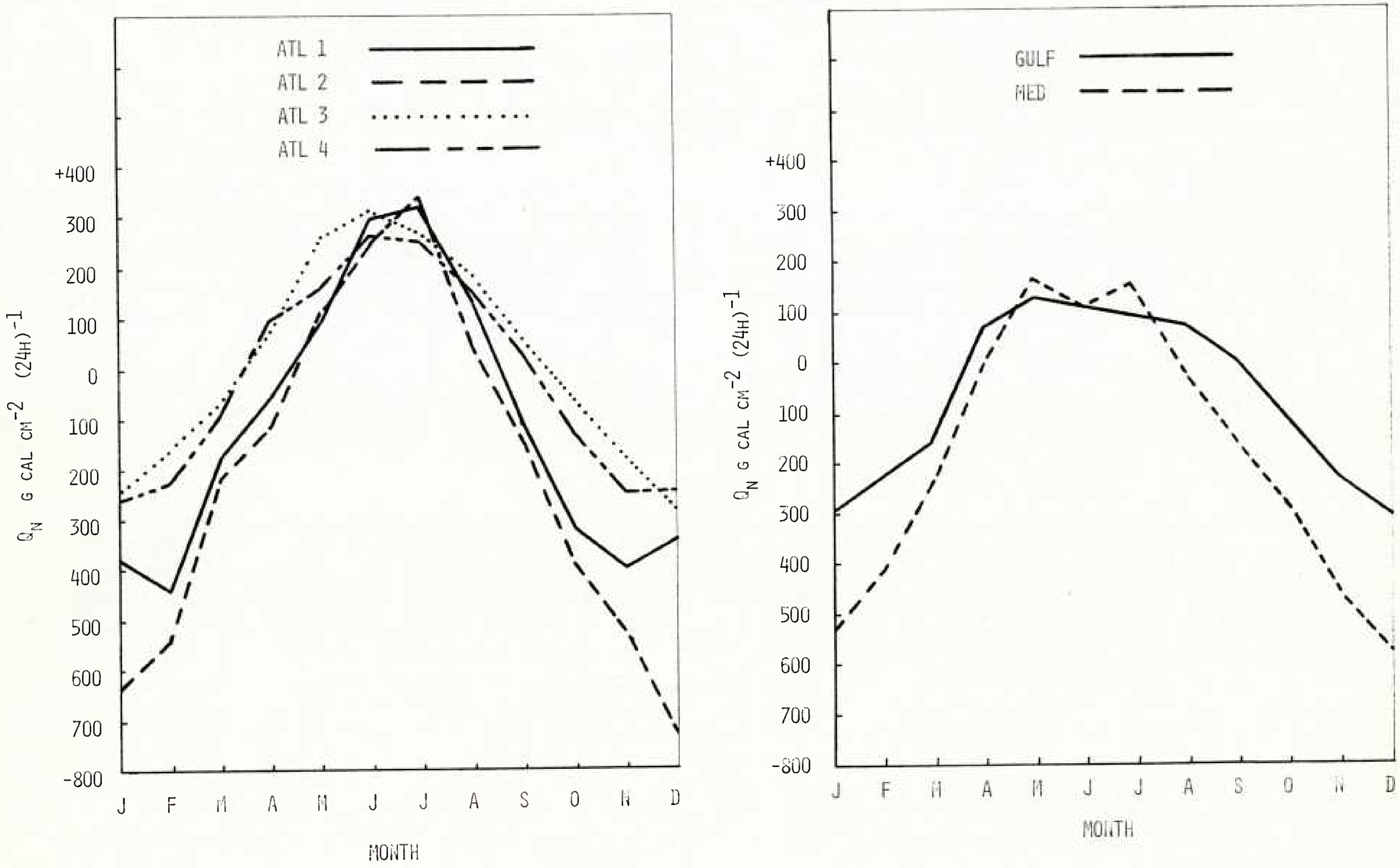


FIGURE 44 MONTHLY MEAN TOTAL HEAT EXCHANGE IN THE OCEANIC REGIONS IN NORTH PACIFIC OCEAN IN 1967

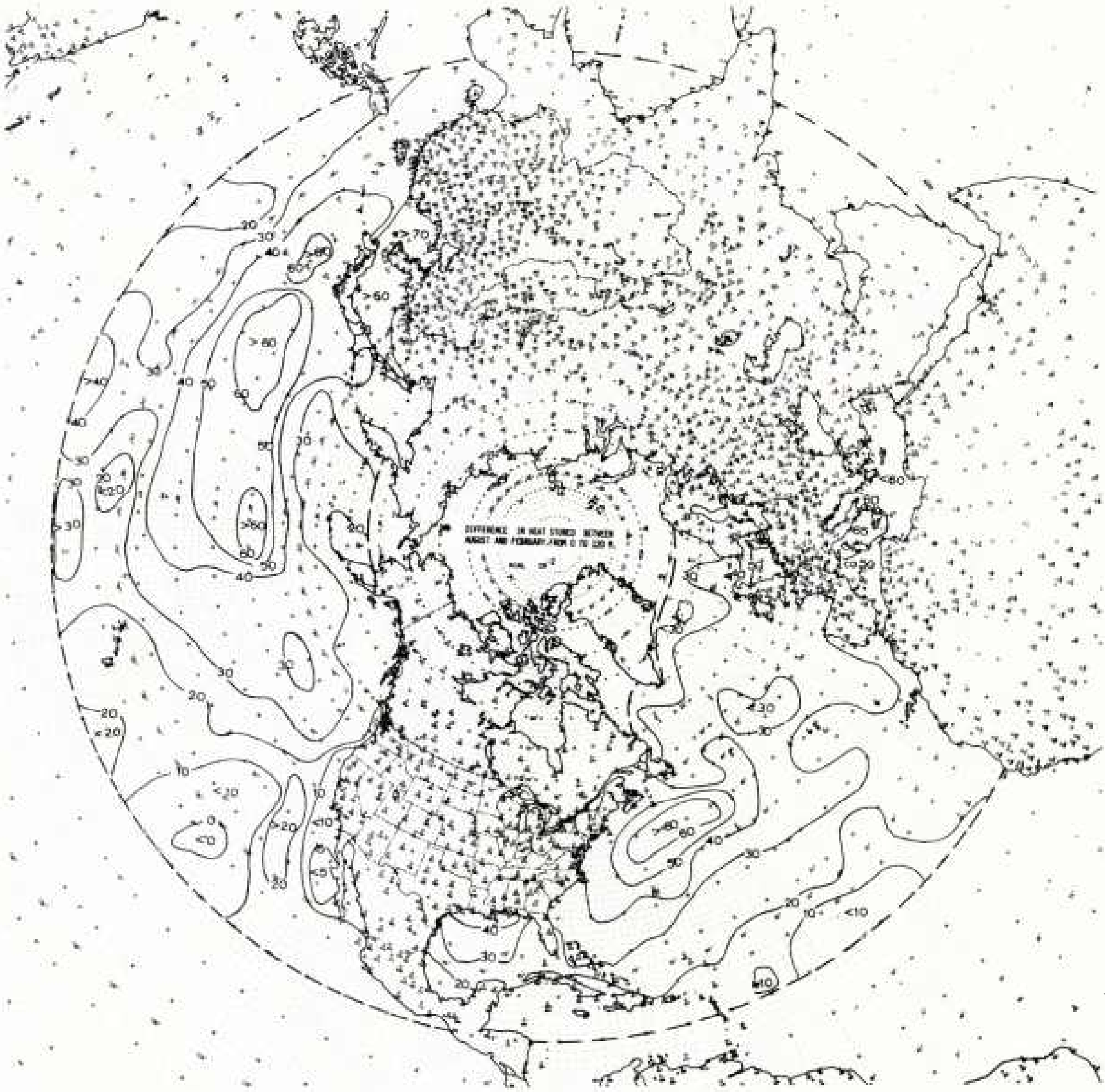


Figure 45 Difference in heat storage in the oceans north of 15° N between February and August from surface to 120 m. depth (kcal cm^{-2})

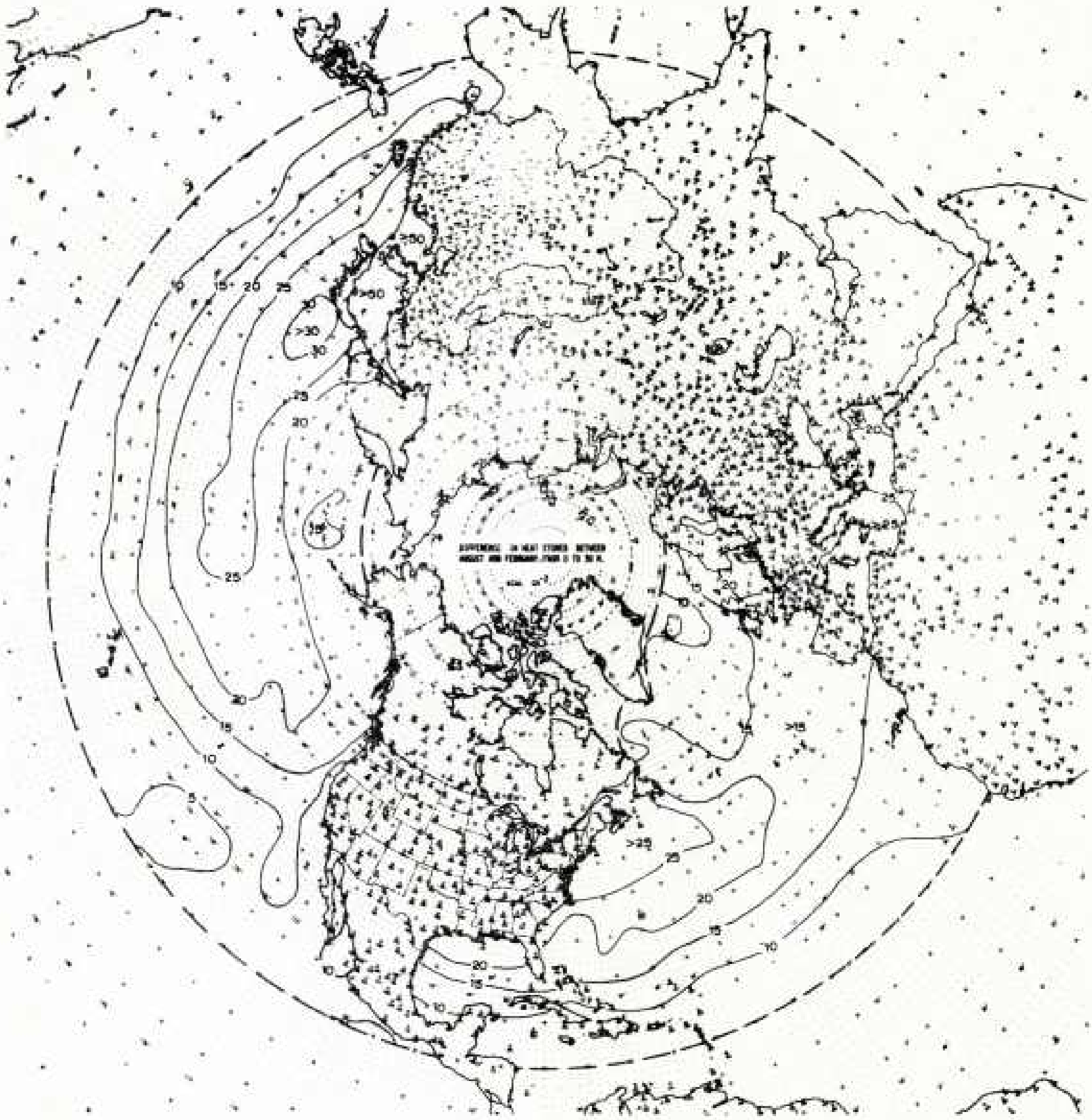


FIGURE 46 DIFFERENCE IN HEAT STORAGE IN THE OCEANS NORTH OF 15°N BETWEEN FEBRUARY AND AUGUST FROM 0 TO 30 M. DEPTH (KCAL CM^{-2})

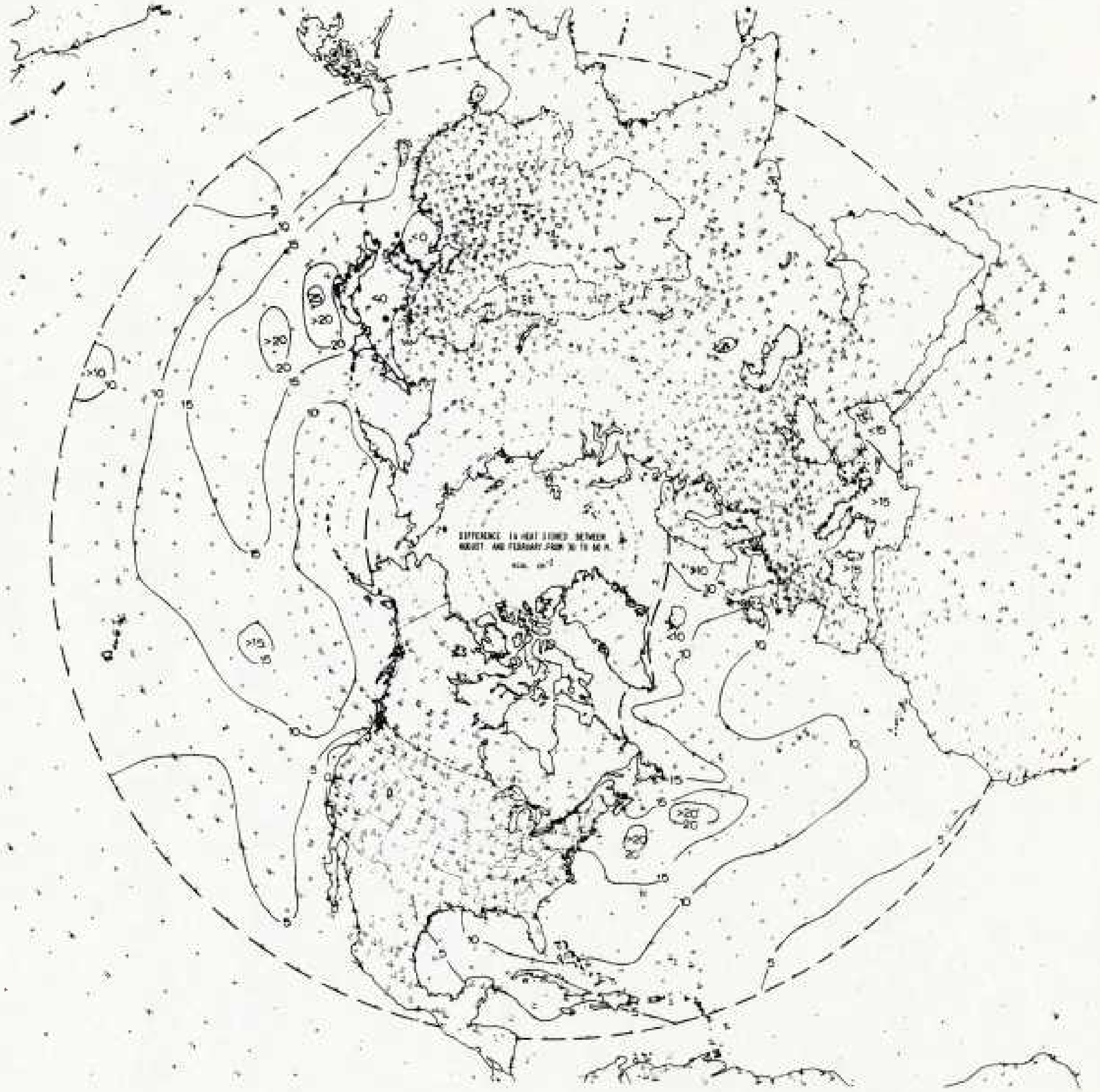


FIGURE 47 DIFFERENCE IN HEAT STORAGE IN THE OCEANS NORTH OF 15 N BETWEEN FEBRUARY AND AUGUST FROM 30 TO 60 M. DEPTH (KCAL CM^{-2})

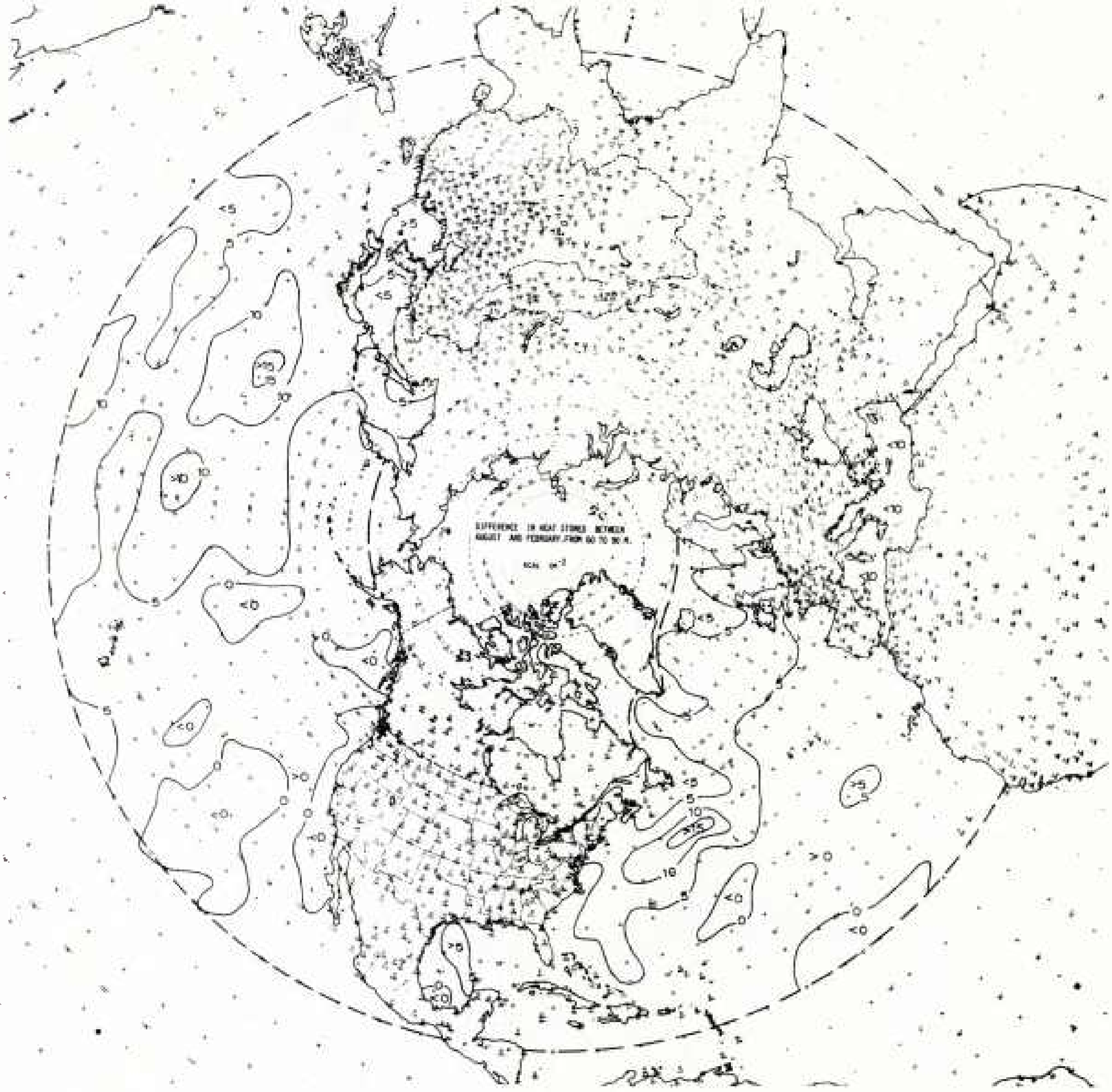


FIGURE 48 DIFFERENCE IN HEAT STORAGE IN THE OCEANS NORTH OF 15 N BETWEEN FEBRUARY AND AUGUST FROM 60 TO 90 M. DEPTH (KCAL CM^{-2})

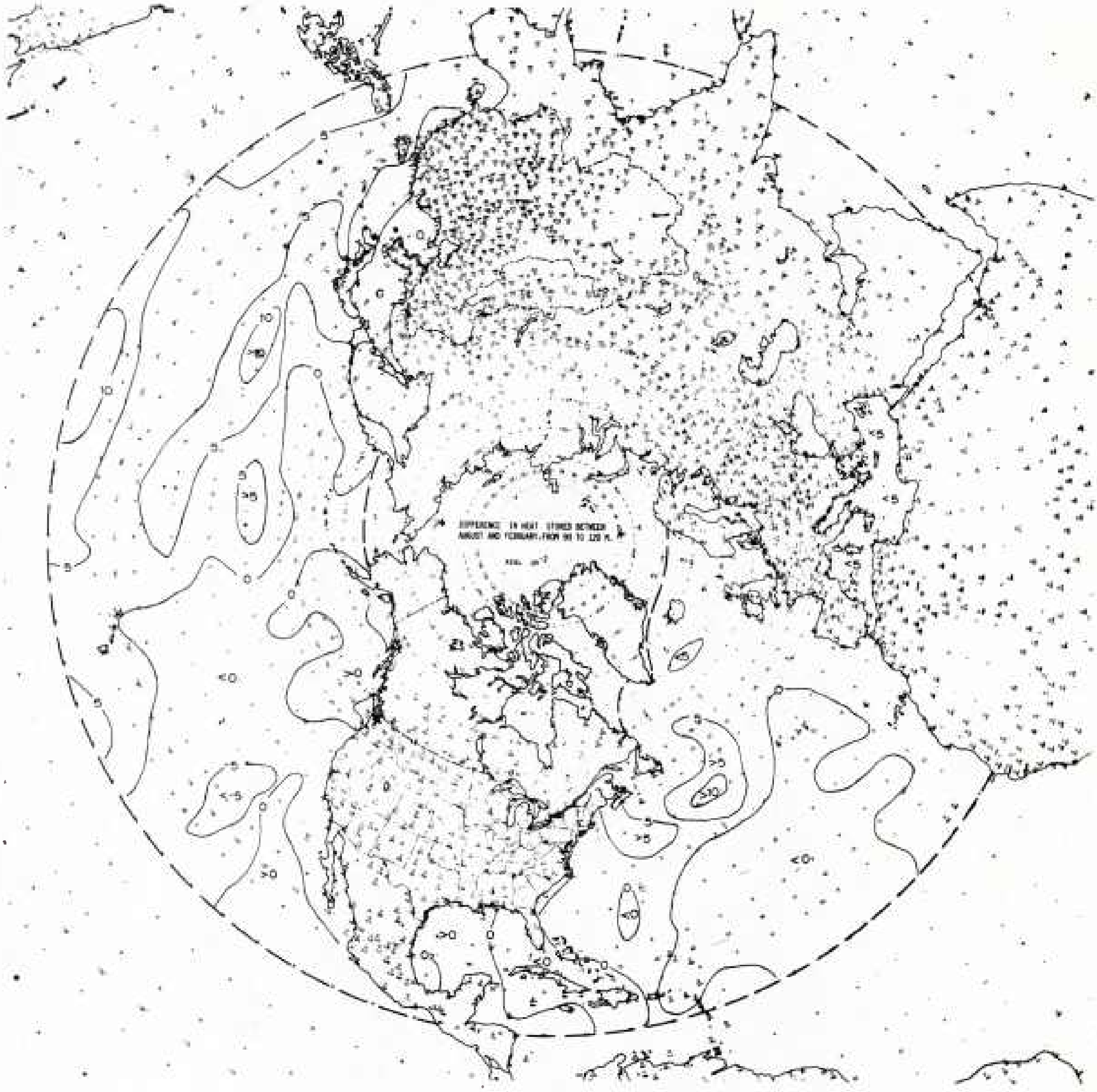


Figure 49 Difference in heat storage in the oceans north of 15 N between February and August from 90 to 120 m. depth (kcal cm^{-2})

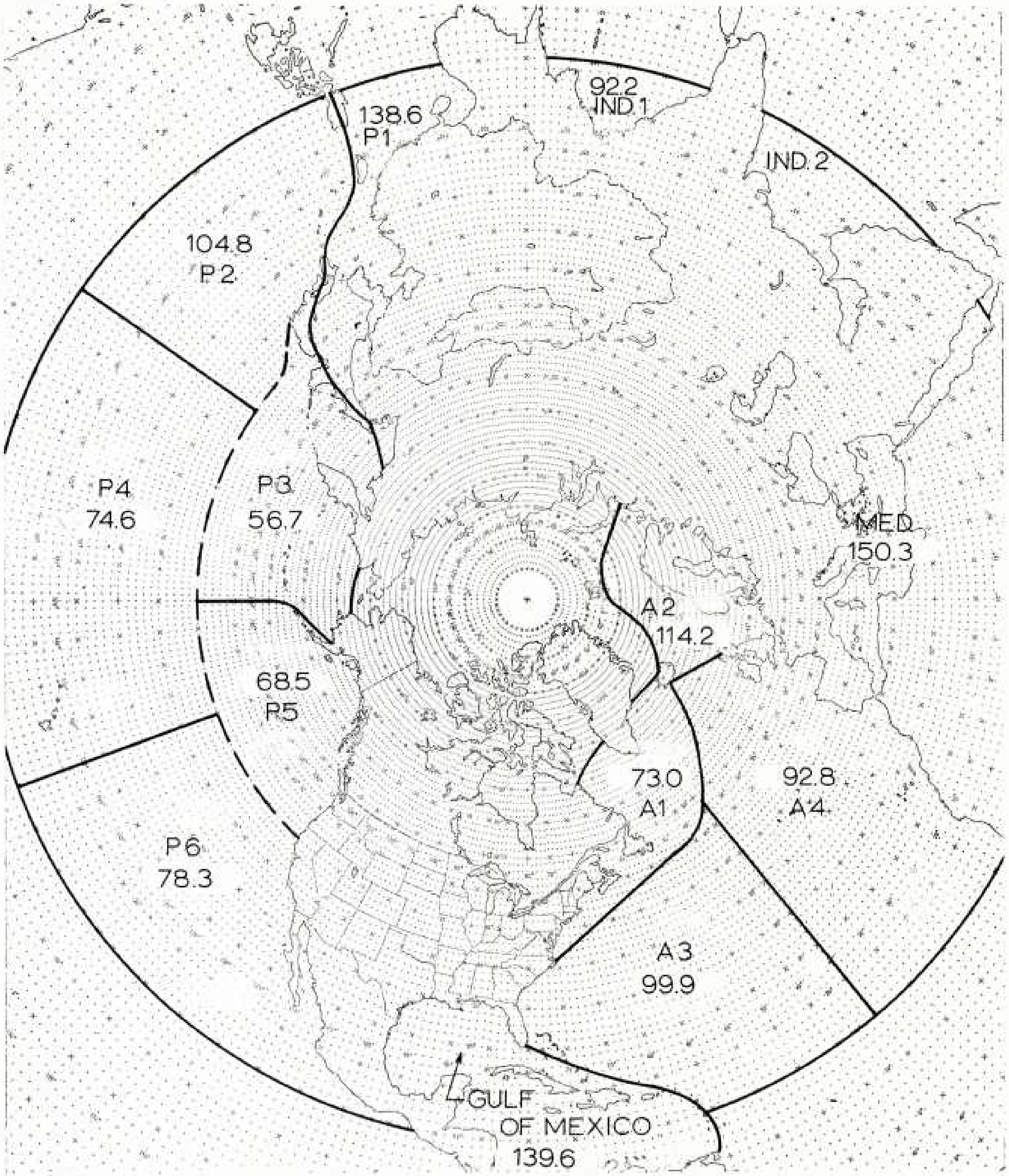


FIGURE 50 RESULTANT SENSIBLE AND LATENT HEAT EXCHANGE IN THE OCEANIC REGIONS DURING 1967
($KCAL\ CM^{-2}\ YEAR^{-1}$)

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART NO. 6-B

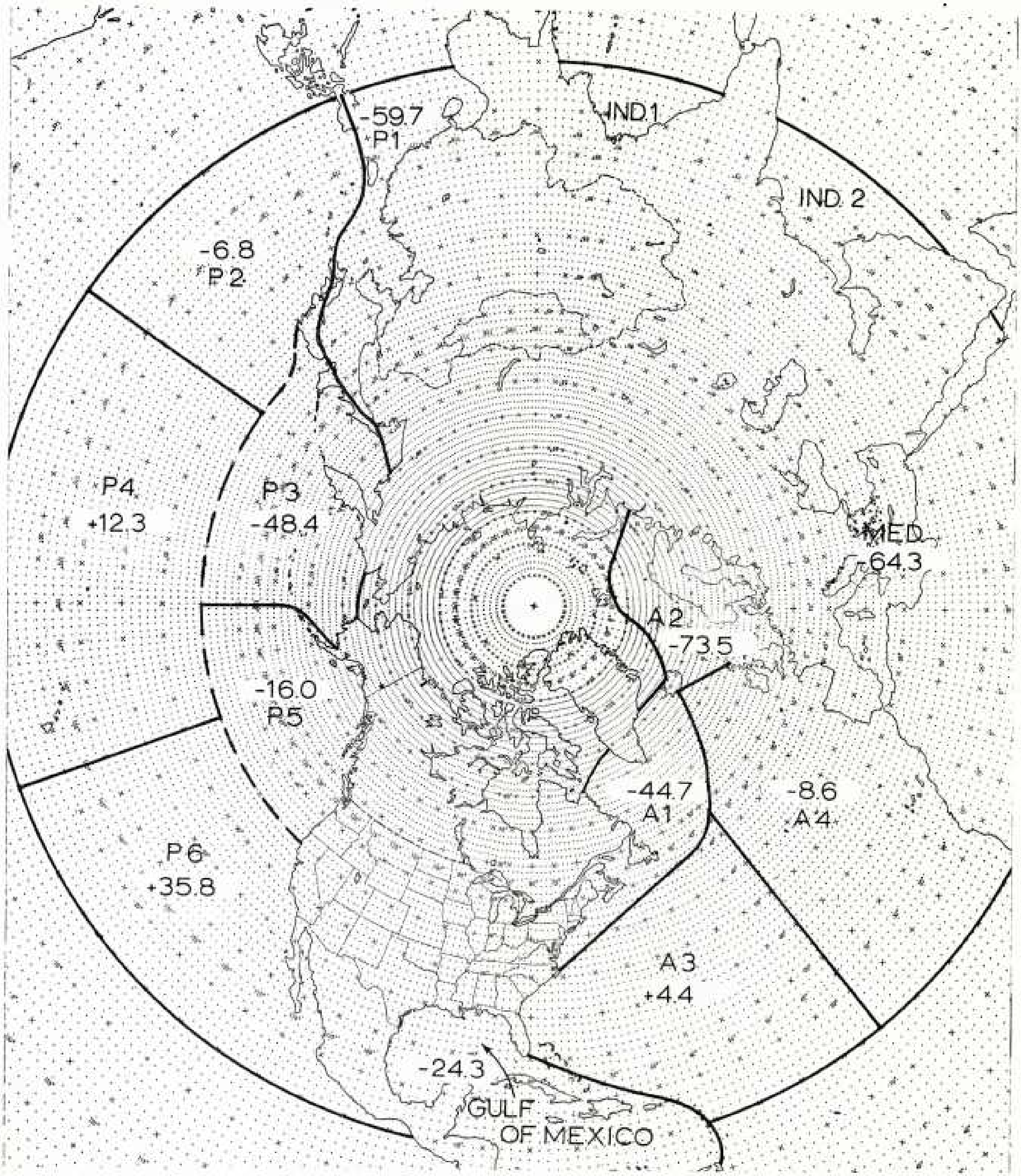


FIGURE 51 RESULTANT TOTAL HEAT EXCHANGE IN THE OCEANIC REGIONS DURING 1967 (KCAL CM^{-2} $YEAR^{-1}$)

PROJECTION: POLAR STEREOGRAPHIC—TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART NO. 6-B

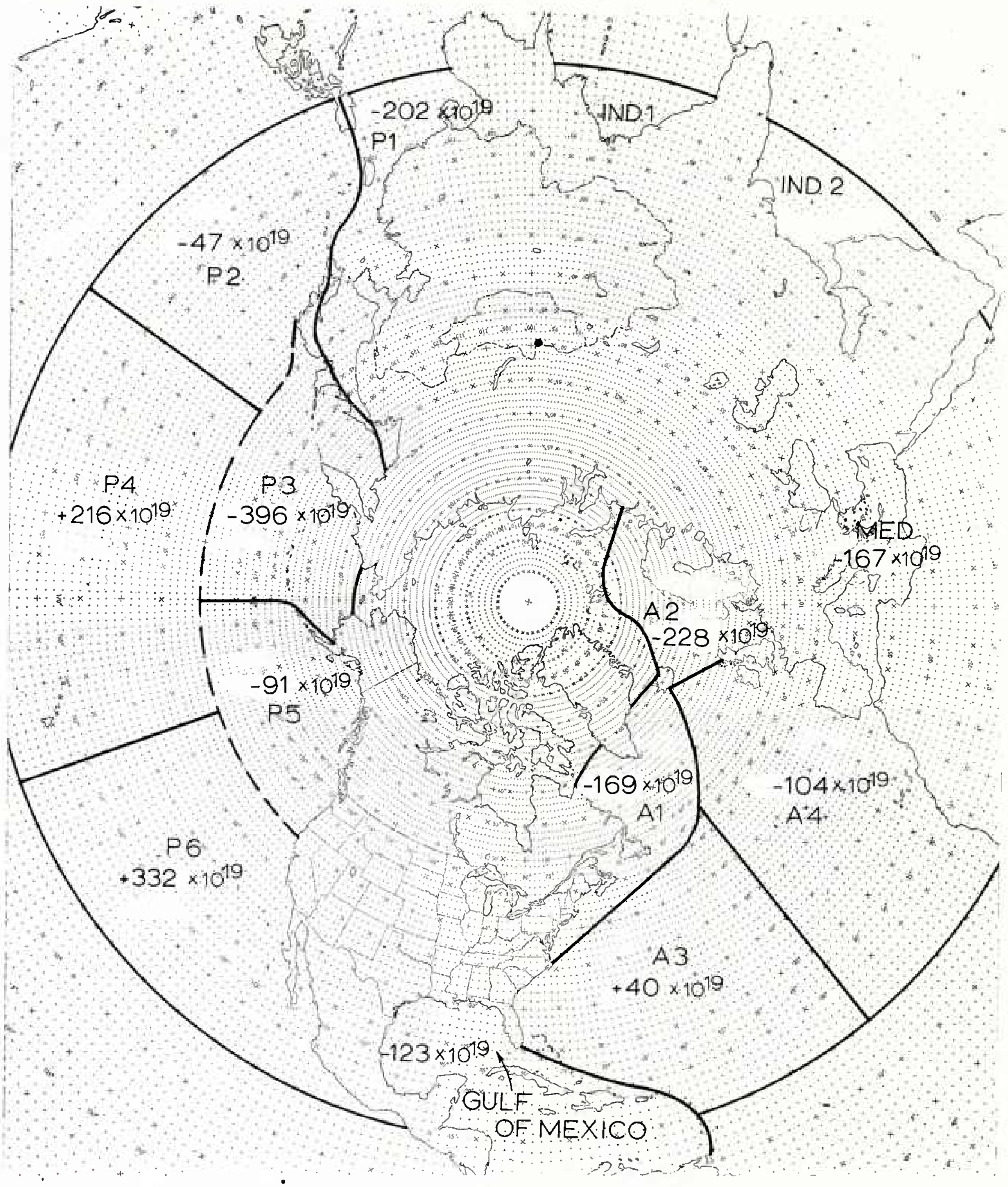


FIGURE 52 TOTAL HEAT GAIN OR LOSS OF THE OCEANIC REGIONS IN 1967 (CAL YEAR^{-1})

PROJECTION: POLAR STEREOGRAPHIC--TRUE AT 60° NORTH LATITUDE
SCALE: 1:60,000,000

FLEET NUMERICAL WEATHER FACILITY
MONTEREY, CALIFORNIA

CHART NO